Appendix B: DFG San Miguel Island Red Abalone Surveys (2006, 2007, 2008)

-Final Report-
The San Miguel Island Red Abalone Resource: Results of a Survey Conducted in Late August, 2006

(Prepared: August 27, 2007)

Introduction

In late August 2006 the California Department of Fish and Game (DFG), California Abalone Association (CAA), and several other collaborators conducted an intensive abalone survey in the shallow sub-tidal waters surrounding San Miguel Island. San Miguel Island (SMI), the northwestern most island in California's Channel Islands, is located approximately 45 miles southwest of Santa Barbara (Figure 1).

The purpose of the report is to provide the San Miguel Island Abalone Fishery Advisory Group (AAG), and other interested parties with a description and documentation of the data gathered and methods used during the survey (metadata) to facilitate effective use of the data. Additionally, the report provides survey results linked to a subset of the management questions surrounding the current red abalone fishery consideration process.

Figure 1. Location of San Miguel Island in relation to the Southern California Bight and the other northern Channel Islands.

Summary of Results

Significant time and effort were expended conducting the 2006 SMI red abalone survey collaboratively, but important information was gathered on the conditions and population status for red abalone. During the survey, 52 divers on 10 vessels covered 202 survey stations in a five day period. This information and experience gained through the survey provide both essential information for initiating the fishery consideration process and designing future surveys. However, additional survey information will be needed in the near future to provide a more robust picture of the status of the population. Several key

results from the survey will be pertinent to the AAG's discussions of potential management alternatives.

1. **Abalone Density:** The overall mean density for the survey was 1,200 abalone per hectare (ab./ha.) and the mean densities by survey zone ranged from 160 ab./ha. in the northwest to 1,600 ab./ha. in the southwest. Abalone density is very patchy with a wide range of high and low densities by site. Additional density survey information is needed to more accurately assess the population abundance and status. In particular, a more accurate assessment of the total possible abalone habitat is needed. Any management structure should consider the patchy nature of abalone populations.
2. **Size Frequency:** The 2006 survey revealed that a large portion of the emergent abalone population is of legal size according to past fishery minimum size limits. While not counted, cryptic abalone were seen under rocks that appeared to be below legal size, indicating that at least some recruitment has occurred. If a fishery is considered, ongoing surveys of recruitment should be incorporated into the management structure. This will help ensure that adaptive management takes into account reproductive success.
3. **Health Survey:** Disease is a potential issue within the population, with a majority of sampled animals testing positive for the WS-RLP bacterium. This will be a major factor to take into account in considering a sustainable fishery and total allowable catch, because the onset of warm water conditions could cause the expression of WS, and thus high mortality rates in infected animals. More pathological studies are planned to better understand the etiology of the disease during varying oceanographic temperature regimes.
4. **Population Estimates**: Based on the density information derived from the survey and using greatest extent kelp coverage from multiple annual aerial kelp surveys, some general population estimates were generated. These population estimates are crude due to the assumption that abalone habitat is equated to all rocky habitat covered by kelp. In reality actual abalone habitat is some sub-set of the overall rocky habitat covered by kelp. Unfortunately at this time more refined estimate of abalone habitat is not possible. None-the-less, these general population estimates are useful in the development of the TAC methodology and to the AAG discussion of allocation and management measure charges.
5. **Habitat Analysis (Substrate, Relief, Algae):** Habitat and algal variables collected during the survey were not strongly correlated with abalone abundance. Clearly, variables other than the ones measured in 2006 are controlling abundance. Thus identification of optimal red abalone habitat will likely require the identification and measurement of different variables. The identification of optimal abalone habitat is important in refining population estimates. A thorough assessment of the usefulness of habitat and algal characterization data collected in 2006 is needed. Similar to population patchiness and clustering, habitat availability should be considered in potential management alternatives.
6. **Abalone Clustering or Aggregation:** Aggregation is a very important component to assessing the status of the overall population and its ability to withstand harvest pressures. The general analysis of abalone clustering by 10 m^2

areas from this survey is limited in its use. This method can only show the percentage of completely solitary animals in the sampled population. More detailed information on the proportion of the population in aggregations, along with the size structure and abundance within aggregations is needed. The next survey plans to include some nearest neighbor assessment to better characterize aggregation. Protection of aggregations may also be a consideration in management options.

7. **Survey Power Analysis:** Ability to scientifically detect changes in the population (power analysis) has significant implications for fishery management when using density level criteria. This single survey provides little power to detect small changes, especially at a low overall density. This inability to detect small changes in density would inhibit the sensitivity of management changes around established density criteria. However, the caveat to this analysis is that it can be done with a time series of independent surveys which may increase precision to detect change over time. The planned 2007 survey and ongoing surveys will be critical to both fishery consideration and ongoing management of any proposed fishery.

Background

In response to depleted stocks and ongoing threats from fishing and other factors, an indefinite moratorium on recreational and commercial abalone fishing south of San Francisco was established in 1997 by Assembly Bill 663 (Thompson). The Thompson bill also mandated the development of an Abalone Recovery and Management Plan (ARMP) to guide the recovery of abalone stocks in southern California, and the management of the extant northern California recreational fishery as well as future fisheries. The ARMP was developed over several years and adopted by the California Fish and Game Commission (Commission) in late 2005 (ARMP 2005).

The ARMP generally identifies an emergent abalone density of 2000 abalone per hectare as the minimum level necessary to protect a population from the risk of collapse in the absence of a fishery. This level is referred to as the Minimum Viable Population (MVP) level (Shepherd and Brown 1993; Babcock and Keesing 1999). Chapter 6 of the final (12/9/05) version of the ARMP also establishes detailed criteria for southern California stock recovery when fisheries may again be considered by the Commission. In addition to the ARMP's general stock recovery and fishery consideration criteria, Section 6.3 of the ARMP allows for consideration of fisheries in specific locations prior to the achievement of full recovery, and identifies the red abalone resource at SMI as the first subject for fishery consideration prior to full recovery.

The ARMP's identification of the red abalone resource at SMI as the initial subject of pre-full recovery fishery consideration is based on several premises, including:

- The current existence of a viable population at SMI,
- A broad size range in the population at SMI, and
- The presence of abalone in established no-take reserves at SMI that may

help ensure continued abalone populations during potential fisheries elsewhere at the Island.

The August 2006 survey was designed to both confirm and strengthen the information underlying these premises and to provide area-specific abalone density and size frequency information potentially useful for developing fishery alternatives for consideration by the Commission. Survey objectives associated with fishery development, include:

1) For the purposes of identifying potential fishable areas, delineate the specific location and extent of areas around SMI where the abalone exhibit a broad size range and viable-level emergent densities.
2) For the purpose of potential future fishery-effects monitoring, establish a baseline comparison of abalone density and size distribution between SMI's established no-take areas and potential fishable areas.
3) For the purpose of facilitating development of the Total Allowable Catch (TAC) component of fishery alternatives, estimate the current total abundance and density of emergent abalone at SMI, and the abundance and density within specific areas where potential future fisheries may be located.
4) For the purpose of engaging the assistance of stakeholders in current and future assessment and monitoring activities, conduct a broad collaborative survey including training, and participation in survey design and sampling methods.

Survey Methods

Detailed descriptions of methods and operations are contained in three other documents prepared in connection with the 2006 survey. The three documents, all attached as appendices to this report, are:

1) **Appendix A**: a survey protocol document,
2) **Appendix B**: a Cruise Report (Stein et al. 2006), and
3) **Appendix C**: a Health Examination Report.

The following is an abbreviated description of the methods employed during the survey, derived from the documents listed above.

Sampling Design: Kelp coverage in the nearshore areas surrounding SMI, as delineated by earlier aerial photography, was used as a proxy for identifying abalone (rocky bottom) habitat (Figure 2). The nearshore areas of SMI were divided into four "zones" (Southwest, Southeast, Northwest, and Northeast). The Northeast zone was not sampled during the August 2006 survey primarily because this zone contained relatively little potential abalone habitat. The three sampled zones were further subdivided using the one nautical mile square California Recreational Fishing Survey (CRFS) blocks ("grids").

The targeted total number of stations to be sampled in each zone was established at a level designed to achieve sampling coverage of at least 0.3% of the total potential abalone habitat within each zone (Table 1). Stations were randomly distributed within the zones as follows:

1) 30 randomly located points were selected within the kelp coverage area of each grid.
2) The proportion of a zone's total number of stations to be located within a particular grid was set equal to the proportion of total zone kelp coverage present in the grid.
3) The appropriate number of points (as per step "2", above) within each grid were randomly selected from the 30 points. These selected points became that grid's potential stations. Alternate stations were also randomly selected within each grid.

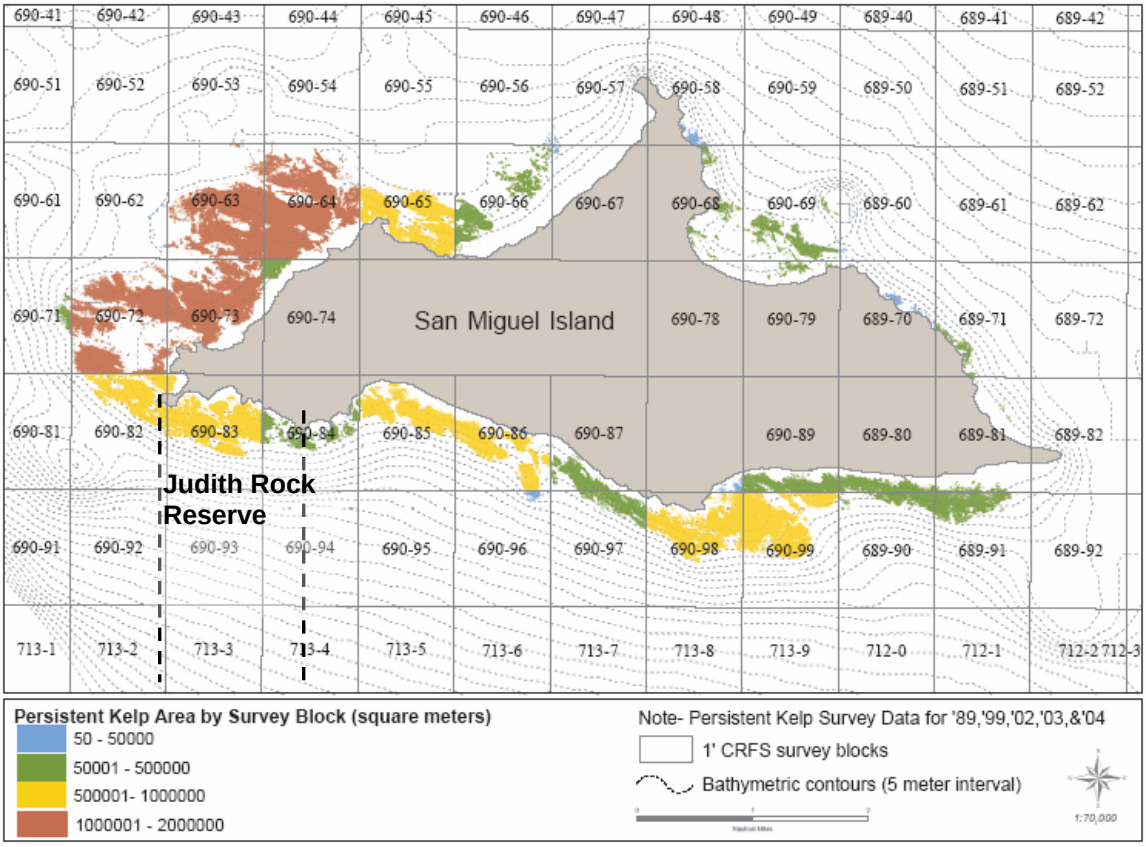

Figure 2. Map of persistent kelp coverage from aerial kelp flight census.

Transect Methodology: The sampling locations each day of the survey were largely dictated by weather conditions at SMI (Appendix B). Dive teams were assigned stations each day by the Biologist in Charge. The dive teams were deployed to assigned stations located using Global Positioning System (GPS) units and the station coordinates. Each station was pre-determined and recorded on station data sheets.

Two 30- meter by 4-meter transects were sampled at each station. The first transect was made along a pre-determined randomly selected compass heading from the station. The second transect was made along the reciprocal heading. If primary stations or heading could not be sampled or were clearly not in abalone habitat, alternative stations and/or transect headings were used (Appendix A).

Sampling Methodology: Sampling along the transect was conducted in two, 2- meter-wide swaths on either side of the transect line (left and right) with one diver on each side of the line. Each diver counted all abalone (recorded in 2 m by 5 m segments on the data sheet), measured the first 30 red abalone encountered, and recorded habitat type, habitat relief, and depth at certain points along their side of the line. Certain dive teams that were experienced in transect sampling were also tasked to count kelp (*Macrocystis*) plant stipes along the transect.

All emergent abalone (observable by the naked eye without the use of flashlights or disturbance of the substrate) encountered within the transect were counted. Other abalone species were identified and measured for size and noted on the data sheet separate from the red abalone counts and measurements.

Depths along each transect were recorded at four different points along the line (0, 10, 20, 30 m). The percent habitat relief and habitat type was recorded by 2 m by 10 m segments of the line. Percent habitat relief was coded by three height categories; Low: < 1 m height; Medium: 1 – 3 m height; and High: > 3 m height. Habitat type was coded by four categories; Reef: non-movable rock; Boulder: moveable rock > 0.5 m; Cobble: Rock < 0.5 m; and Sand: as on a beach. Divers swam the transect line several times to be able to collect and record all the data. *Macrocystis* counts were done by counting the number of stipes on each plant and recording the counts by 10 m segments on the data sheet. All data was recorded on waterproof datasheets and data was immediately tallied and summarized immediately after each dive. Completed data sheets were given to a data management team on board the boat as soon as possible each day.

Survey Results

A tremendous amount of survey data was generated during the five days of sampling. A description of the day to day work, logistics and participants on the cruise is provided in the appended Cruise Report. During the cruise, 202 survey stations with 400 transects were sampled, and 5695 abalone counted. Due to inclement weather, the majority of stations surveyed occurred in the two southern survey zones, which were protected by the island from the strong prevailing northwest winds (Table 1).

Table 1. Summary of completed grids, stations, transects, and abalone counted per survey zone.

Zone	Grids Surveyed	Stations Surveyed	Transects Surveyed	Abalone Counted
Northwest	4	30	60	116
Southeast	7	79	157	2024
Southwest	8	93	183	3555
Totals	19	202	400	5695

Abalone Density: When data from all stations and zones are combined, the overall average density was 1200 abalone per hectare (ab./ha.). A total of 48,000 m^2 (4.8 ha.) of bottom habitat was surveyed. The southwest zone had the highest density and the most completed transects (Table 2). Abalone density in the northwest zone was approximately one-tenth that of the southwest zone.

Table 2. Mean red abalone density overall and by zone.

Zone	Total Area (m^2)	No. of Abalone	Density (No./Ha.)	SE	No. of Transects
Northwest	7200	116	160	50	60
Southeast	18840	2024	1100	150	157
Southwest	21960	3555	1600	170	183
Overall	48000	5695	1200	100	400

ARMP section 6.3.1 mentions the existence of no-take reserves at San Miguel as an additional insurance for continued abalone populations if stocks were depleted nearby under a possible future fishery. The only no-take reserve that was sampled during the survey is the Judith Rock Reserve located in the southwest zone. The reserve extends from Judith Rock on the west end of Tyler Bight west to Adams Cove near Point Bennett (Figure 2). A comparison of mean densities inside and outside of the reserve (the remainder of the southwest zone) is provided in Table 3. The other no-take area at SMI, Harris Point State Marine Reserve (SMR), is located in the unsampled Northeast Zone,.

Table 3. Abalone density comparison inside and outside of the Judith Rock Reserve.

Area	Total Area (m^2)	No. of Abalone	Density (No./Hectare)	SE	No. of Transects
Judith Rock Reserve	5160	644	1200	260	43
Outside Reserve (SW Zone)	16800	2911	1700	210	140
Total	21960	3555	1600	170	183

Red abalone distribution at SMI during the August survey was quite patchy, with emergent abalone density levels among stations ranging from zero to over 6,000 individuals per hectare.

Size Frequency: During the cruise, 3957 red abalone were measured. The size frequency for all zones and each individual zone is depicted in Figures 3 and 4. Using the current northern California recreational minimum size (178 mm or 7 inches) and the past pre-1997 southern California commercial minimum size (197 mm or 7.75 inches), 70% and 38% of the observed emergent abalone were of legal recreational and commercial size, respectively. A possible increased minimum size limit (203 mm or 8 inches) was also examined and 27% of emergent abalone were at or above that size limit.

The Southwest zone showed the greatest proportion of legal size abalone and the Northwest zone the lowest (Table 4). Both the Southwest and Southeast zones showed similar size frequency distributions with most of the animals skewed towards the larger sizes. The Northwest zone did not show the same size pattern and had more individuals represented in the smaller size classes.

Table 4. Percentage of abalone by size category and zone.

Size Category	Zone		
	Southeast	Southwest	Northwest
Sub-legal (<178 mm)	33%	27%	71%
Recreational (>= 178 mm)	67%	73%	29%
Commercial (>= 197 mm)	34%	42%	11%
Higher Size Limit (>= 203 mm)	23%	30%	9%

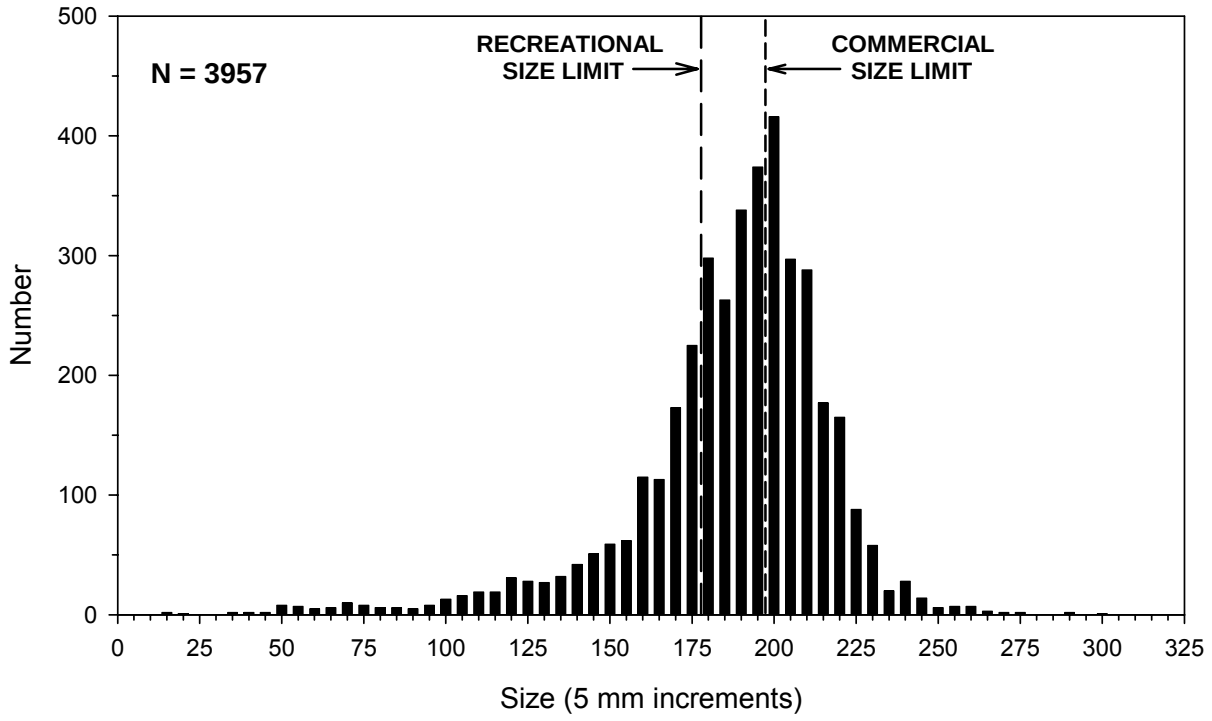

Figure 3. Overall size frequency for the San Miguel Island Survey, August 27-31, 2006

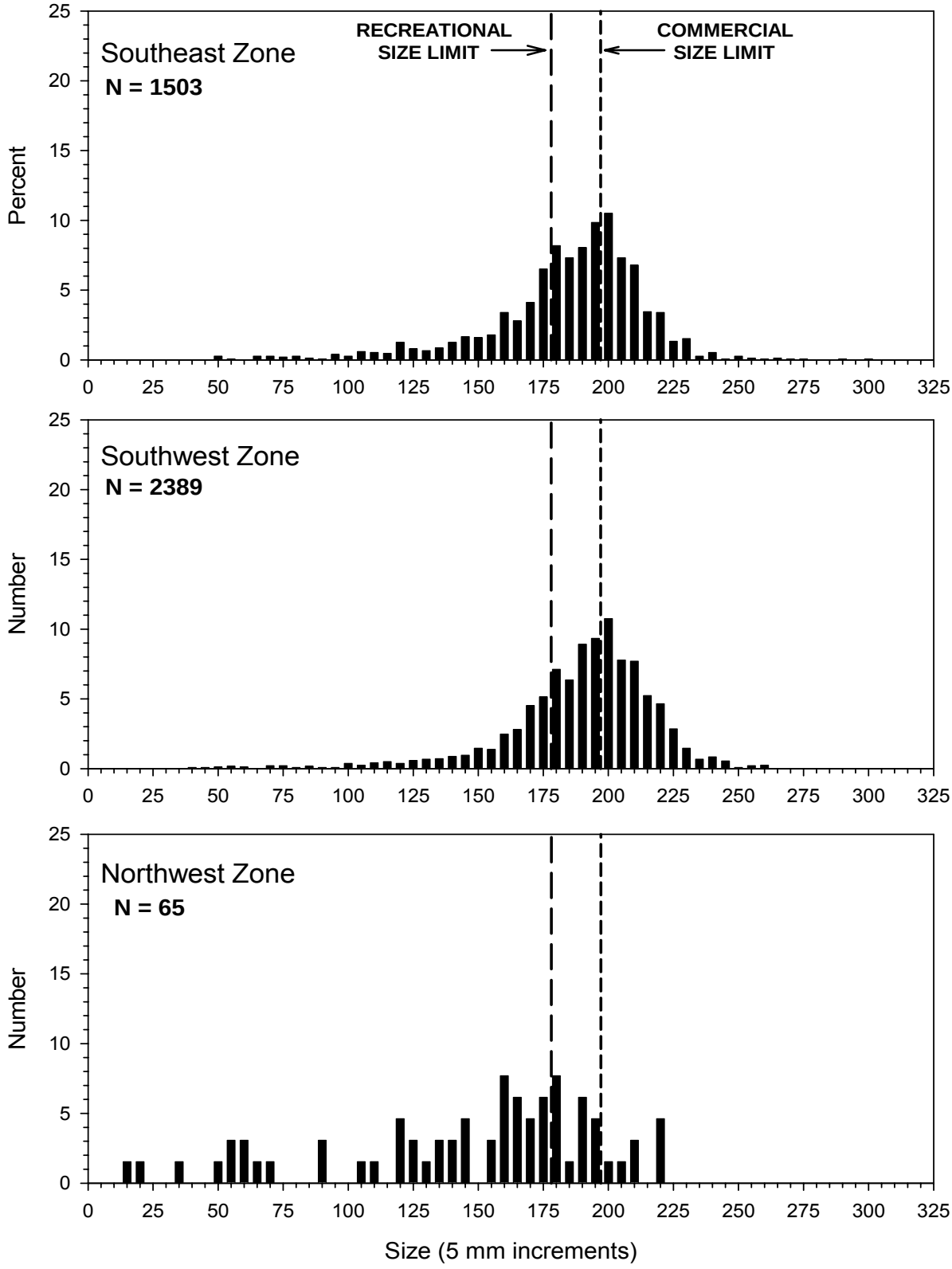

Figure 4. Percent size frequency of red abalone by zone, San Miguel Island survey. August 27-31, 2006.

Abalone Health Survey: During the cruise, 52 abalone of varying size were collected for a health exam. Animals were sent to the Department's Shellfish Health Laboratory in Bodega Bay, CA. for examination. In general, animals in the sample did not show any physical signs of Withering Syndrome (WS) (ie. shrunken body mass, anomalies in body weight etc.). However, the sample showed varying rates of infection among individuals with the Withering Syndrome-Ricketsia Like Prokaryote (WS-RLP) bacteria. The WS-RLP is known to infect all species of abalone in California waters. The actual clinical signs of WS are manifested only during times of warm water influence (> 18º C) such as El Niño events. In this limited sample, 58% of the abalone were infected with WS-RLP, including 12% with high infection intensities. The lack of visible body shrinkage and generally high body mass condition indexes indicate that relatively cool waters are providing thermal refuge from the effects of this pathogen. A more detailed report on the health exam is provided in Appendix C.

A reproduction assessment was conducted on a subsample of red abalone collected from San Miguel Island for the abalone health examination. Of the 54 red abalone sampled for health, 27 were subsampled to determine their reproductive condition. A total of 18 females were sampled 12 of which were greater than 178mm. For these 12 the average size was 198mm (SD 11) with an average body weight excluding the shell of 930 g (SD170). This sample had an average number of mature oocytes of 19.98 million eggs per female. All 18 females had normal ovary structure. The smallest female sampled 104mm did not have any eggs. The remaining 9 individuals in the subsample were males greater than 174mm. These 9 males were sampled for the presence of spermatocyts and testes structure. All males had normal testes structure and spermatocyts.

Population Estimates: Abalone population was estimated by multiplying densities for each zone by abalone habitat estimated from kelp surveys of San Miguel Island conducted in the years 1989, 1999, 2002, 2003, 2004, 2005, and 2006 (Tables 5 and 6). The maximum coverage of kelp combined for all years was used for the calculations. Two sets of estimates were made using the mean density (Table 5) and the lower 95% confidence limit density (Table 6).

Table 5. Abalone population estimates using maximum kelp area and mean density.

Zone	Maximum Kelp Area (m2)	Mean Estimate	Abalone >= 178 mm (7 inches)	Abalone >= 197 mm (7.75 inches)	Abalone >= 203 mm (8 inches)
Northwest	**7,880,000**	**127,000**	**37,000**	**14,000**	**12,000**
Southeast	**3,490,000**	**373,000**	**251,000**	**128,000**	**86,000**
Southwest (excludes Judith Rock SMR)	**2,410,000**	**410,000**	**299,000**	**172,000**	**123,000**
Overall	**13,780,000**	**910,000**	**587,000**	**314,000**	**221,000**

Table 6. Abalone population estimates using maximum kelp area and 95% lower confidence limit density.

Zone	95% Lower Limit Estimate	Abalone >= 178 mm (7 inches)	Abalone >= 197 mm (7.75 inches)	Abalone >= 203 mm (8 inches)
Northwest	**48,000**	**14,000**	**5,000**	**4,000**
Southeast	**270,000**	**182,000**	**92,000**	**62,000**
Southwest (excludes Judith Rock SMR)	**313,000**	**228,000**	**131,000**	**94,000**
Overall	**806,000**	**550,000**	**300,000**	**212,000**

The initial zones were established for the purposes of conducting the San Miguel Island survey and might be too large to be effectively used in management of a potential fishery. Two smaller zones were selected from the southwest and southeast survey zones in areas with relatively high abalone densities for possible use as management zones (Table 7, Figures 5,6). A population estimate for these zones was calculated using maximum kelp area and average abalone densities in each management zone. Estimates for numbers of abalone in commercial size categories were made using percentages in size ranges for each survey zone.

Table 7. Abalone population estimates for possible management zones 1, 2, 3, and 3a.

Zone	Density (Abs/Ha)	SE (Abs/Ha)	Maximum Kelp Area (Ha)	Abalone Population Estimate	Abalone >= 178 mm (7 inches)	Abalone >= 197 mm (7.75 inches)	Abalone >= 203 mm (8 inches)
SW 1	**2400**	**300**	**88**	**211,000**	**154,000**	**89,000**	**63,000**
SW 2	**1500**	**300**	**45**	**68,000**	**49,000**	**28,000**	**20,000**
SE 3	**2000**	**300**	**132**	**264,000**	**177,000**	**90,000**	**61,000**
SE 3a	**1700**	**200**	**178**	**302,000**	**203,000**	**103,000**	**70,000**

Abalone populations by depth range and zones were calculated using percent of stations in each depth range in each zone (Table 8). The distribution by depth would be useful information if management practices have a depth factor similar to the northern California SCUBA prohibition which protects abalone in deeper waters.

Table 8. Abalone population estimates by depth.

Zone	10-30 feet	30-50 feet	50-70 feet
Northwest	**1,000**	**102,000**	**22,000**
Southeast	**199,000**	**165,000**	**7,000**
Southwest	**292,000**	**292,000**	**29,000**

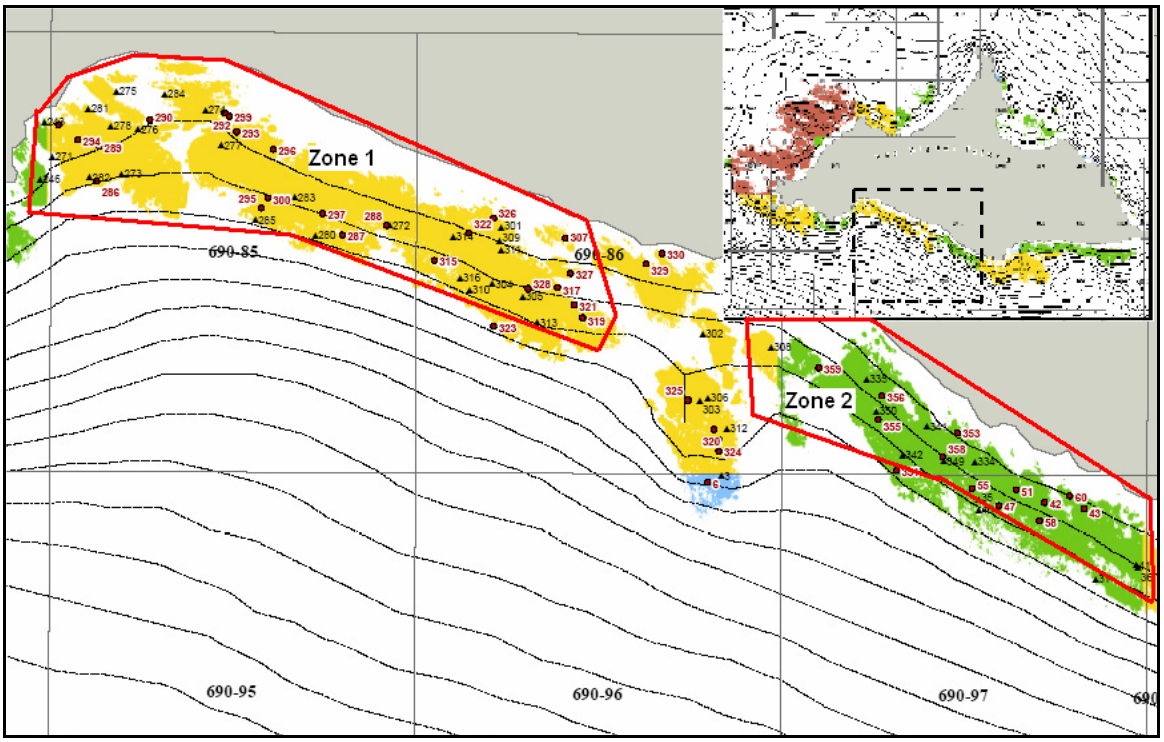

Figure 5. Southwest management zones 1 and 2.

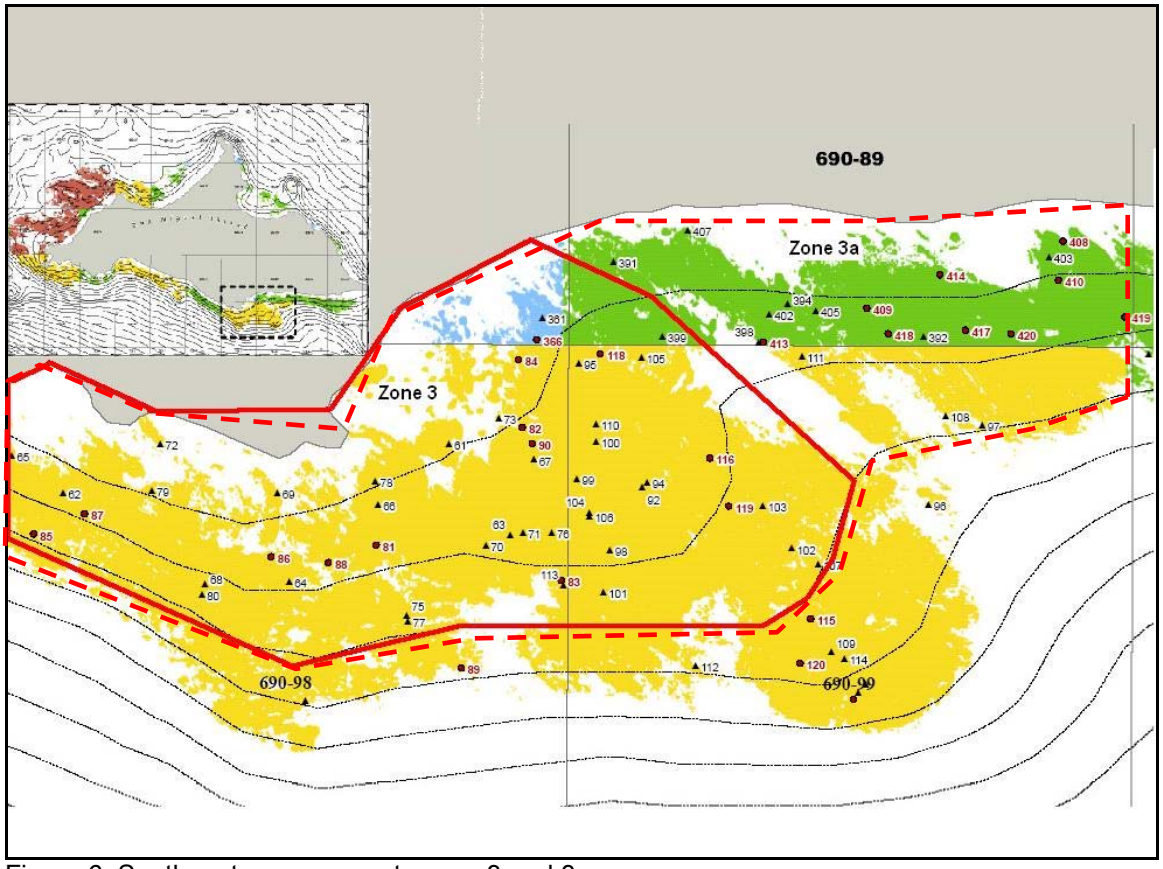

Figure 6. Southeast management zones 3 and 3a.

Observed Substrate and Relief for Survey Transects

Hard substrate was observed in 94% of the area surveyed for all zones combined and was the dominant substrate in all zones ranging from 80-85% (Table 9). The Southeast zone had more sand by percentage (17%) than the other zones.

Table 9. Percentage of hard substrate (reef, boulder, and cobble) and sand for surveyed transects at three zones.

Zone	Hard Substrate	Sand	Unrecorded Substrate
Northwest	94%	5%	1%
Southwest	83%	11%	6%
Southeast	80%	17%	3%
All Zones	85%	11%	4%

The hard substrate for all zones comprised of mostly reef (64%), with boulder (12%), and cobble (9%) being less common (Table 10). More boulder was observed in the Southwest zone (16%), and more cobble was observed in the Northwest zone (18%). Sand was observed more often in the Southeast transects at 17% of the total for the zone.

Hard substrate was the dominant substrate for surveyed transects for all zones. Survey protocols required that transects be placed under kelp canopy and on greater than 50% suitable abalone habitat, so it was expected that most of the habitat surveyed was either reef, boulder, or cobble.

Table 10. Percentage of reef, sand, boulder, and cobble for surveyed transects at three zones.

Zone	Reef	Sand	Boulder	Cobble	Unrecorded Substrate
Northwest	64%	5%	13%	18%	0%
Southwest	61%	11%	16%	7%	5%
Southeast	67%	17%	9%	4%	3%
All Zones	64%	11%	12%	9%	4%

Mostly low relief substrate was observed during the survey, comprising 68% of the bottom for all zones combined (Table 11). However, low relief was more commonly observed in the Northwest (73%) and Southeast (78%) zones, than in the Southwest zone (53%). Medium relief (30%) and high relief (11%) was most commonly observed in the Southwest zone.

Table 11. Percentage of low, medium, and high relief type for three zones at San Miguel Island.

Zone	Low	Medium	High	Unrecorded Relief
Northwest	73%	18%	9%	0%
Southwest	53%	30%	11%	6%
Southeast	78%	15%	3%	4%
All Zones	68%	21%	8%	3%

A backward stepwise regression analysis was performed to assess whether an association occurred between station substrate characteristics (reef, boulder, cobble, sand substrate; low, medium, and high relief) and abalone density. A significant relationship (test of regression model, $F(2,199) = 8.47$, $P<0.001$) occurred between habitat type and abalone density for all transects in three zones using % reef ($P=0.012$) and % medium relief ($P=0.001$) covariates. However, the $R^2 = 0.08$ was low, showing that the covariates accounted for only a small amount of the variation in abalone densities. A significant relationship (regression test, $F(1,28)=18.3$, $p<0.001$) occurred in the Northwest zone for abalone density and % boulder ($P<0.001$). The $R^2 = 0.40$ was much higher. For the Southwest zone, a significant relationship (regression test, $F(1,88)=10.8$, $P=0.001$) occurred between abalone density and mean depth ($p=0.001$). The $R^2 = 0.11$ was low. The Southeast zone had a significant relationship (regression test, $F(2,76)=12.2$, $p<0.001$) between abalone density and % reef ($P=0.003$) and % medium relief ($P<0.001$) covariates. The $R^2 = 0.24$ was somewhat low.

The Northwest and Southwest zones were comprised mostly of low relief substrate with small percentages of high and medium relief compared to the Southeast zone. Although significant correlations between abalone density and relief type were not found, abalone would most likely favor areas of medium to high relief, which would be characterized by larger ledges and cracks in which abalone inhabit.

The highest R^2 value was found in the Northwest. However, the sample size was much smaller than the other two zones, where very weak or no relationship was found. Using these tests, there appears to be no way to statistically predict abalone density using the substrate variables chosen for this survey.

Count of Giant Kelp (*Macrocystis*) Plants and Stipes for Survey Transects

Giant kelp plants and stipes were counted on 107 transects, totaling 12840 m^2 of observed area (Table 12). More area was surveyed in the Southwest (5280 m^2) than the other two zones. Mean stipe count per plant was highest in the Southwest zone (9.5) and lowest in the Northwest zone (5.3), however, the Northwest zone had the highest density of plants per m^2 (0.42) than observed in the other two zones; 0.41 in the Southeast and 0.34 in the Southwest.

Table 12. Summary of algal data for all zones at San Miguel Island.

	Northwest	Southwest	Southeast	All Zones
Transects	**26**	**44**	**37**	**107**
Area Sampled (m^2)	**3120**	**5280**	**4440**	**12840**
***Macrocystis* Plants**	**1322**	**1773**	**1838**	**4933**
***Macrocystis* Stipes**	**6959**	**16868**	**14545**	**38372**
Mean Stipes per *Macrocystis*	**5.3**	**9.5**	**7.9**	**7.8**
***Macrocystis* per m^2**	**0.42**	**0.34**	**0.41**	**0.38**

Most plants observed in the Northwest zone were small (69.14%) with a stipe count of 1-5 per plant (Table 13). Approximately 90% of all observed plants had 10 or less stipes per plant.

Plant density was higher in the Northwest zone compared to the other zones, but the the plants themselves were smaller in size, indicating that they are younger plants. The Northwest zone is more exposed to wind and swell than the other zones, and it is likely the kelp plants here more often get ripped out, which may account for the dominance of younger plants.

Larger plants (plants with higher numbers of stipes) were more common in the two southern zones.(Table 13).

A linear regression analysis showed no relationship between abalone density and *Macrocystis* plant counts in the Northwest zone (t test, t= -0.89, df=11, p=0.39) and for the Southwest zone (t test, t= -0.91, df=24, p=0.37). Significant relationships between abalone density and *Macrocystis* plant counts occurred for the Southeast zone (t test, t= -2.41, df=17, p=0.03) and for all three zones combined (t test, t= -2.13, df=56, p=0.04).

Abalone Clustering

Abalone clustering or aggregation is defined as the close grouping of abalone that form highly effective spawning assemblages. Since abalone are broadcast spawners, both sexes must be in close proximity (≈ <= 1 m) for successful spawning to occur. Thus a measure of the percentage of the overall population that are in aggregations is an important piece of information for management. A measure of abalone clustering was developed by enumerating the frequency and percentage of solitary and clustered abalone in 5 x 2 meter segments. This is a preliminary attempt at measuring the number of abalone groupings within the smallest spatial resolution possible from the survey (10 m^2 area).

Abalone were encountered in 29.7% of all 5 x 2 m segments. Solitary abalone were only 8.1% of the 5695 abalone counted in 5 x 2 meter segments (Table 14). Most of the abalone counted were in groups of two or more (91.9%), which accounts for 5234 of the abalone.

Table 14. Frequency of abalone group sizes per 5 x 2 meter sector for all zones combined.

Group Size	Frequency	Total Abalone	% of Total Abalone	% of Total Segments
0	3374	0	0	70.3%
1	459	459	8.1%	9.6%
2	276	552	9.7%	5.8%
3	158	474	8.3%	3.3%
4	128	512	9.0%	2.7%
5	99	495	8.7%	2.1%
6	58	348	6.1%	1.2%
7	48	336	5.9%	1.0%
8	36	288	5.1%	0.8%
9	41	369	6.5%	0.9%
10	24	240	4.2%	0.5%
11	17	187	3.3%	0.4%
12	12	144	2.5%	0.3%
13	11	143	2.5%	0.2%
14	9	126	2.2%	0.2%
15	11	165	2.9%	0.2%
16	4	64	1.1%	0.1%
17	7	119	2.1%	0.2%
18	8	144	2.5%	0.2%
19	1	19	0.3%	0.0%
20	5	100	1.8%	0.1%
21	2	42	0.7%	0.0%
22	1	22	0.4%	0.0%
23	4	92	1.6%	0.1%
24	2	48	0.8%	0.0%
25	2	50	0.9%	0.0%
28	1	28	0.5%	0.0%
30	1	30	0.5%	0.0%
33	3	99	1.7%	0.1%
Total	4802	5695	100.0%	100.3%

These data show that most of the abalone are clustered into groups of 2 or more for a 10 m^2 of area. Over a quarter of the counted abalone (28.3%) were observed in groups of 10 or more per 10 m^2 of area.

For the Northwest zone, abalone were encountered in just 8.3% of the total segments and solitary abalone made up 25.9% of the abalone counted (Table 15). Solitary abalone were also 50% of the total groups. Abalone in groups of 2 or more were observed 74.1% of the time.

Table 15. Frequency of abalone group sizes per 5 x 2 meter sector for the Northwest zone.

Group Size	Frequency	Total Abalone	% of Total Abalone	% of Total Segments
0	660	0	0	91.7%
1	30	30	25.90%	4.2%
2	20	40	34.50%	2.8%
3	4	12	10.30%	0.6%
4	1	4	3.40%	0.1%
5	2	10	8.60%	0.3%
6	1	6	5.20%	0.1%
7	2	14	12.10%	0.3%
	720	116	100.00%	100.1%

In the Southwest zone, abalone were observed in 39.9 % of the segments and 7.8% of the abalone counted were solitary and 92.2% were observed in groups of 2 or more (Table 16). In the Southeast zone, 26% of the segments had abalone with 7.5% of the segments having solitary animals and 92.5% were in groups of two or more (Table 17).

Table 16. Frequency of abalone group sizes per 5 x 2 meter sector for the Southwest zone.

Group Size	Frequency	Total Abalone	% of Total Abalone	% of Total Segments
0	1321	0	0	60.1%
1	278	278	7.8%	12.7%
2	164	328	9.2%	7.5%
3	102	306	8.6%	4.6%
4	79	316	8.9%	3.6%
5	63	315	8.9%	2.9%
6	39	234	6.6%	1.8%
7	29	203	5.7%	1.3%
8	17	136	3.8%	0.8%
9	28	252	7.1%	1.3%
10	15	150	4.2%	0.7%
11	9	99	2.8%	0.4%
12	7	84	2.4%	0.3%
13	9	117	3.3%	0.4%
14	3	42	1.2%	0.1%
15	7	105	3.0%	0.3%
16	2	32	0.9%	0.1%
17	5	85	2.4%	0.2%
18	7	126	3.5%	0.3%
19	1	19	0.5%	0.1%
20	2	40	1.1%	0.1%
21	2	42	1.2%	0.1%
22	1	22	0.6%	0.1%
23	2	46	1.3%	0.1%
24	1	24	0.7%	0.1%
25	1	25	0.7%	0.1%
30	1	30	0.8%	0.1%
33	3	99	2.8%	0.1%
	2198	3555	100.0%	100.3%

Table 17. Frequency of abalone group sizes per 5 x 2 meter sector for the Southeast zone.

Group Size	Frequency	Total Abalone	% of Total Abalone	% of Total Segments
0	1393	0	0	74.0%
1	151	151	7.5%	8.0%
2	92	184	9.1%	4.9%
3	52	156	7.7%	2.8%
4	48	192	9.5%	2.6%
5	34	170	8.4%	1.8%
6	18	108	5.3%	1.0%
7	17	119	5.9%	0.9%
8	19	152	7.5%	1.0%
9	13	117	5.8%	0.7%
10	9	90	4.4%	0.5%
11	8	88	4.3%	0.4%
12	5	60	3.0%	0.3%
13	2	26	1.3%	0.1%
14	6	84	4.2%	0.3%
15	4	60	3.0%	0.2%
16	2	32	1.6%	0.1%
17	2	34	1.7%	0.1%
18	1	18	0.9%	0.1%
20	3	60	3.0%	0.2%
23	2	46	2.3%	0.1%
24	1	24	1.2%	0.1%
25	1	25	1.2%	0.1%
28	1	28	1.4%	0.1%
	1884	2024	100.0%	100.4%

Survey Power Analysis

A power analysis of the 2006 abalone survey data was conducted to assess the ability to detect density increases or decreases observed in future surveys. The analysis was done on the number of abalone counted per survey station at an error rate of 5% (alpha = .05) and a power of 0.8 (Table 18). Table 20 shows a list of potential density estimates and the corresponding number of stations that would need to be sampled for that density value to be statistically significant in discerning change between the 2006 and 2007 survey. Due to the high level of variation in abalone counts, the ability to detect small changes in density would require a larger amount of sampling than was conducted in 2006. For example, 77 stations would be needed to detect an increase of 89% (0.159 to 0.300) in abalone density in the Southwest zone. Thus we are only able to statistically discern large changes in density under our current sampling regime.

Table 18. 2006 survey power analysis for the 2007 survey.

2007				
Density	Regress	Samp size to detect Pop.change		
#/sq. m.	Sigma	nw	se	sw
0.010	0.0293			
0.015	0.0356			
0.030	0.0545	>2000		
0.060	0.0923	41		
0.100	0.1427	26	>2000	
0.150	0.2057	21	269	>2000
0.200	0.2687	19	103	529
0.250	0.3317	18	51	183
0.300	0.3947	18	38	77
0.350	0.4577	17	32	52
0.400	0.5207	17	28	41
Samp Size 2006		30	79	93
mean 2006		0.0161	0.1068	0.1593
sigma 2006		0.0282	0.1752	0.2022

Alpha = .05; Power = 0.8

Conclusion

The information gained from the August 2006 survey has helped to achieve the four survey objectives associated with fishery development mentioned in the beginning. The four survey objectives are:

1) Identify potential fishable areas and delineate the specific location and extent of areas around SMI where the abalone exhibit a broad size range and viable-level emergent densities.
2) Establish a baseline comparison of abalone density and size distribution between no-take areas and potential fishable areas for the purpose of potential future fishery-effects monitoring,.
3) To facilitate development of the TAC component of fishery alternatives, by estimating the current total abundance and density of emergent abalone at SMI, and the abundance and density within specific areas where potential future fisheries may be located,.
4) conduct a broad collaborative survey including training, and participation in survey design and sampling methods to engage the assistance of stakeholders in current and future assessment and monitoring activities

The broad area random survey has identified several areas that could potentially sustain a fishery (small scale management zones SW 1 and SE 3) that exhibit a broad size range and viable-level emergent densities. The survey has also provided baseline population levels for both inside and outside of reserve stocks that can provide vital fishery effects information in the future.

Abalone abundance and size data from the survey will help inform and be used in

development of a TAC component for fishery alternatives. Broad population estimates based on density and kelp coverage as a proxy for habitat was generated for the purpose of TAC discussion and development. Finally, the survey has provided a template for continued future cooperative constituent surveys. A similar cooperative survey for 2007 is already planned.

The 2006 survey has provided a sound basis from which further studies can build upon to assess and describe the status of the abalone population at SMI. Several studies will be initiated this year based on information collected in 2006. The health survey provided useful good information on the occurrence of WS-RLP that can cause WS within the population at SMI. The next study will build upon this information by determining the potential impacts of a possible El Niño event on health and survival. Another study that will begin in 2007 will help define a baseline aggregation index for the population. The degree of aggregation with in the population is important to know for determining reproductive potential and assessing allee effects at low population levels. Both studies, the "Investigation of the Potential Impact of El Niño Events on San Miguel Island Red abalone Health and Survival" and the "Developing Baseline Aggregation Indexes for Red Abalone at San Miguel Island" have already begun.

In addition to the two new studies mentioned above, population assessment surveys will continue with the 2007 survey to add to the knowledge base established for SMI red abalone.

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The San Miguel Island Red Abalone Resource: Results of a Survey Conducted from July-October 2007

Marine Region Invertebrate Management Project

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December 2008
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THE RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME

The San Miguel Island Red Abalone Resource: Results of a Survey Conducted from July-October 2007

Introduction

In 2007 the California Department of Fish and Game (Department), California Abalone Association (CAA), and several other collaborators conducted an intensive red abalone (*Haliotis rufescens*) survey in the shallow sub-tidal waters surrounding San Miguel Island (SMI). The surveys were conducted during four research cruises from July through November. SMI is the northwestern most island in California's Channel Islands, located approximately 45 miles southwest of Santa Barbara (Figure 1). The 2007 survey is the second year of a multi-year effort to characterize the population status of red abalone around SMI. Survey results will be used in the ongoing process to evaluate the possibility of opening a limited abalone fishery at SMI.

The purpose of this report is to provide a description and documentation of the data gathered and methods used during the survey (metadata). The findings from the 2007 survey will be compared to the 2006 survey (Taniguchi et al., 2006). Additionally, this report interprets survey results with respect to related management questions regarding the current red abalone fishery consideration process at SMI.

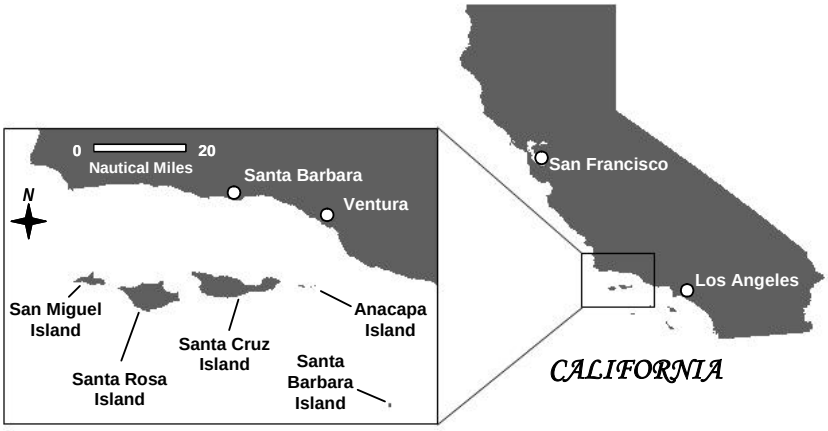

Figure 1. Location of San Miguel Island in relation to the Southern California Bight and the other northern Channel Islands.

Summary of Results

As with the 2006 survey, significant time and effort were expended conducting the 2007 collaborative SMI red abalone survey, and important information was gathered on the conditions and population status for red abalone. During the survey, 38 individual divers on 7 vessels covered 133 survey stations during four cruises over eleven days. This information and experience gained through the survey coupled with the 2006 survey

provides additional essential information for informing the fishery consideration process and designing future collaborative surveys. Several key results from the survey, as well as comparisons and differences from past SMI surveys, will be pertinent to the SMI Abalone Fishery Advisory Group (AAG) discussions of potential management alternatives.

1. **Abalone Density:** The overall mean density for the survey was 1,100 abalone per hectare (ab/ha) and the mean densities by survey zone ranged from 100 ab/ha in the Northwest to 1,400 ab/ha in the Southwest. Abalone density is very patchy with a wide range of high and low densities by site. In comparison, results from the 2006 survey were an overall mean density of 1,200 ab/ha, with 160 ab/ha in the Northwest, and 1,600 ab/ha in the Southwest. Additional density survey information from future surveys is needed to more accurately assess the population abundance, status and the total available abalone habitat. Any management structure should consider the patchy nature of abalone populations.
2. **Size Frequency:** Similar to the 2006 survey, the 2007 survey revealed that a large portion of the emergent abalone population is of legal size with respect to past fishery minimum size limits. The similarity in results between the two surveys serves to validate our data collection methods. Additionally, non-transect efforts revealed small size classes in and out of MPA areas, indicating that recruitment is occurring at SMI. If a fishery is considered, ongoing surveys of recruitment should be incorporated into the management structure. This will help ensure that adaptive management takes into account reproductive success.
3. **Population Estimates**: General population estimates based on the density information derived from the survey, and using greatest extent kelp coverage from multiple annual aerial kelp surveys to represent available habitat, were generated as in the 2006 survey. These population estimates are crude due to the assumption that abalone habitat is equated to all rocky habitat covered by kelp. In reality, actual abalone habitat is some sub-set of the overall rocky habitat covered by kelp. Unfortunately at this time a more refined estimate of abalone habitat is not possible. Nonetheless, these general population estimates may be useful in the development of the Total Allowable Catch (TAC) methodology and to the AAG discussion of allocation and management measure charges.
4. **Habitat Analysis (Substrate, and Relief):** In 2006, the habitat and algal variables measured were not strongly correlated with abalone abundance. Clearly, variables other than the ones examined in 2006 are correlated with abalone abundance. Thus, identification of optimal red abalone habitat will likely require the identification and measurement of additional or different metrics of these variables. The identification of optimal abalone habitat is important in refining population estimates. In 2007, abalone were categorized with respect to the substrate and relief type in which they inhabited. These data may aid in identifying optimal red abalone habitat. Similar to population patchiness and clustering, habitat availability and suitability should be considered in potential management alternatives.
5. **Abalone Clustering or Aggregation:** Aggregation is a very important

component to assessing the status of the overall population and its ability to successfully reproduce. The general analysis of abalone clustering by 10 m^2 units from the 2006 survey was limited in its use. In 2007, a Scripps Institute of Oceanography researcher completed a nearest neighbor study, which better characterized aggregation. The results show that average distances between nearest neighbors and aggregation sizes in the populations are strongly correlated with density. The average nearest-neighbor distance increases dramatically at densities below approximately 2,000 abalone ab/ha, and the average aggregation size is less than 4 abalone at densities close to 2,000 ab/ha. Protection of aggregations may be an important factor in maintaining a healthy population.

6. **Abalone Fecundity Analysis:** Fecundity is important for determining the potential for successful reproduction, which can be utilized in fisheries models. Number of mature eggs and gonad index, an estimate of the volume of gonad tissue, were determined for female abalone at SMI. The results were compared to abalone examined from Van Damme State Park in northern California. Egg counts increased with abalone size (length). SMI abalone possessed a higher number of mature eggs than abalone of similar sizes from Van Damme sites. In addition, the gonad index was higher on average for abalone at SMI.
7. **Survey Power Analysis:** The power of a survey relates to its ability to detect changes in the population over time, and has significant implications for fishery management when using density level criteria. Despite the relatively large numbers of samples (transects) the first survey in 2006 provided little power to detect relatively small density changes, especially at a low overall density. This inability to detect small changes in density could limit the effectiveness of management based upon density criteria, such as that currently prescribed in the Abalone Recovery and Management Plan (ARMP). However, one benefit of this type of analysis is that it can be done with a time series of independent surveys, which may increase its precision in detecting change over time. Abalone densities between the two survey years 2006 and 2007 were not shown to be significantly different given the power of our survey, meaning there either were no significant changes in density, or that they were too small to detect at the sampling level employed. The final survey planned in 2008 and possible ongoing smaller surveys will be critical to both fishery consideration and ongoing management of any proposed fishery.

Background

In response to depleted stocks and ongoing threats from fishing and other factors, an indefinite moratorium on recreational and commercial abalone fishing south of San Francisco was established in 1997 by the state legislature. The legislation also mandated the development of an ARMP to guide the recovery of abalone stocks in southern California, and the management of the extant northern California recreational fishery as well as future fisheries. The ARMP was developed over several years and

adopted by the California Fish and Game Commission (Commission) in late 2005 (ARMP 2005).

The ARMP generally identifies a stepwise process for recovering depleted abalone resources in the moratorium area. The recovery process is tracked through the use of measurable recovery milestones (criteria) from the beginning population status at the start of recovery to the ending population that can provide a sustainable fishery. Chapter 6 of the ARMP establishes detailed criteria for southern California stock recovery when fisheries may again be considered by the Commission. In addition to the ARMP's general stock recovery and fishery consideration criteria, Section 6.3 of the ARMP allows for consideration of fisheries in specific locations prior to the achievement of full recovery, and identifies the red abalone resource at SMI as the first subject for fishery consideration prior to full recovery.

The ARMP's identification of the red abalone resource at SMI as the initial subject of pre-full recovery fishery consideration is based on several factors, including:

- The current existence of a viable population at SMI,
- A broad size range in the population at SMI, and
- The presence of abalone in established no-take reserves at SMI that may help ensure continued abalone populations during potential fisheries elsewhere at the Island.

The 2006 and 2007 surveys were designed to both confirm and strengthen the information in support of these factors and to provide area-specific abalone density and size frequency information potentially useful for developing fishery alternatives for consideration by the Commission. Survey objectives associated with fishery development, include:

1) Delineate the specific location and extent of areas around SMI where the abalone exhibit a broad size range and sufficient emergent densities.
2) Establish a baseline for comparison of abalone density and size distribution between SMI's established no-take areas and potential fishable areas.
3) Estimate the current total abundance and density of emergent abalone at SMI, and the abundance and density within specific areas where potential future fisheries may be located.

Collaborate with stakeholders in current and future assessment and monitoring activities. Conduct a broad survey including stakeholder training, and engage partners in survey design and sampling methods.

Survey Methods

Detailed descriptions of methods and operations are contained in two other documents prepared in connection with the 2007 survey. The two documents, all attached as appendices to this report, are:

1) **Appendix A**: a survey protocol document, and
2) **Appendix B**: a cruise report

Following is an abbreviated description of the methods employed during the survey, derived from the documents listed above.

Sampling Design: Kelp coverage in the nearshore areas surrounding SMI, as delineated by earlier aerial photography, was used as a proxy for identifying abalone (rocky bottom) habitat (Figure 2). The nearshore areas of SMI were divided into four "zones" (Southwest, Southeast, Northwest, and Northeast). The Northeast zone was not targeted for density survey sampling during the 2007 survey primarily because this zone contained relatively little potential abalone habitat. The three sampled zones were further subdivided using the one nautical mile square California Recreational Fishing Survey (CRFS) blocks ("grids").

The targeted total number of stations to be sampled in each zone was established at a level designed to achieve sampling coverage of at least 0.3 percent of the total potential abalone habitat within each zone. Stations were randomly distributed within the zones as follows:

1. Total kelp coverage in each grid was mapped out to a water depth of 50 feet. The depth limit of 50 feet was chosen based on known depth preferences of red abalone at San Miguel Island. This survey limit was further supported by survey results from 2006, which revealed few or no abalone deeper than 50 feet.
2. Thirty randomly located points were selected within the kelp coverage area of each grid.
3. The proportion of a zone's total number of stations to be located within a particular grid was set equal to the proportion of total zone kelp coverage present in the grid.
4. The appropriate number of points (as per step "2", above) within each grid were randomly selected from the 30 points. These selected points became that grid's primary stations. Alternate stations were also randomly selected within each grid.

Figure 2. Map of persistent kelp coverage from aerial kelp flight census.

Transect Methodology: The sampling locations each day of the survey were largely dictated by weather conditions at SMI (Appendix B). Dive teams were assigned stations each day by the Biologist in Charge. The dive teams were deployed to assigned stations located using Global Positioning System (GPS) units and the station coordinates. Each station was pre-determined and recorded on station data sheets. Two 30-meter by 4-meter band transects were sampled at each station. The first transect was made along a pre-determined randomly selected compass heading from the station. The second transect was made along the reciprocal heading. If primary stations or heading could not be sampled or were clearly not in abalone habitat, alternative stations and/or transect headings were used (Appendix A).

Sampling Methodology: Sampling along the transect was conducted in two, 2-meter-wide swaths on either side of the transect line (left and right) with one diver on each side of the line. Each diver counted all abalone (recorded in 2 m by 5 m segments on the data sheet), measured the first 30 red abalone encountered, and recorded habitat type, habitat relief, and depth at certain points along their side of the line. In addition,

divers categorized each abalone into substrate (Reef, Boulder, or Cobble) and relief (Low, Medium, or High) categories which it inhabited.

All emergent abalone (observable without the use of flashlights or disturbance of the substrate) encountered within the band transect were counted. Other abalone species were identified and measured for size and noted on the data sheet separate from the red abalone counts and measurements.

Depths along each transect were recorded at four different points along the line (0, 10, 20, 30 m). The percent habitat relief and habitat type was recorded by 2 m by 10 m segments of the line. Percent habitat relief was coded by three height categories; Low: < 1 m height; Medium: 1 – 3 m height; and High: > 3 m height. Habitat type was coded by four categories; Reef: non-movable rock; Boulder: moveable rock > 0.5 m; Cobble: Rock < 0.5 m; and Sand: as on a beach. Divers swam the transect line several times to be able to collect and record all the data. All data was recorded on waterproof datasheets, and data was immediately tallied and summarized after each dive. Completed data sheets were given to a data management team on board the boat as soon as possible each day.

Swim Survey Methodology: An exploratory swim survey was conducted on two dives in the Harris Point MR where abalone had been documented during past Department cruises. Dive teams swam a predetermined compass heading or route at the site within the reef boundaries. Divers sought suitable rocky habitat to search for abalone. Large cobble and small boulder were turned over to search for juveniles. Abalone were measured, enumerated, and identified. Divers also recorded depth and habitat type where the animal was found.

Analysis of SMI Abalone Fecundity: Abalone were collected at San Miguel Island in the fall of 2006 (n=16) and 2007 (n=62) to determine the gonad index and number of mature eggs per female. Gonad Index is an estimate of the volume of gonad tissue. The methods used for obtaining gonad index and total number of mature eggs are described in Rogers-Bennett et al. (2004b).

Gonad Index: All animals were weighed and the length of the shell was measured. The foot and organs were detached from the shell (shucked) and weighed. Mature female gonad tissue appears dark green in color whereas the male gonad is tan. The length and width of the conical gonadal appendage, including the inner digestive gland core, was measured. Slices were made halfway down the appendage, and the height and width of the gonad/digestive cone and the height and width of the inner core of the digestive gland were measured. The digestive gland is dark brown in color. Gonad volume was estimated by assuming that the digestive gland and gonad are cone shaped. The volume of the inner digestive gland cone was subtracted from the total cone volume to yield the volume of the outer gonad cone as described by Tutschulte (1976), and Tutschulte and Connell (1985). The gonad index was defined as gonad volume *100/abalone body weight.

Total Number of Mature Eggs: Egg number was estimated by counting all the mature eggs in four microscope fields (×200), dividing by the volume of the four fields, and multiplying by the gonad volume. The volume of a microscope field is equal to the area of the field multiplied by the thickness. The area was calculated using an ocular micrometer for field dimensions. The thickness was defined as twice the average oocyte diameter. This is due to the fact that a small mature oocyte section can derive from an oocyte largely above or below the section plane. The average oocyte diameter was 176 um, exclusive of the jelly layer. It was determined by measuring the diameter of 1,000 of the largest, roundest oocytes in the sections, and by measuring fresh oocytes.

Survey Results

A tremendous amount of survey data was generated during the eleven days of sampling. A description of the day to day work, logistics, and participants on the cruise is provided in the appended Cruise Report. During the cruise, 133 survey stations with 259 transects were sampled, and 3,501 abalone counted. The Northwest zone accounted for 19 percent of the transects, but only 1 percent of the counted abalone, the Southeast made up 25 percent of transects and 30 percent of the counted abalone, and the Southwest made up 56 percent of the transects and 69 percent of the counted abalone (Table 1).

Table 1. Summary of completed grids, stations, transects, and abalone counted per survey zone.

Zone	Total Grids	Total Stations	Total Transects	Total Abalone
Northwest	**6**	**25**	**50**	**47**
Southeast	**6**	**33**	**65**	**1,044**
Southwest	**7**	**75**	**144**	**2,410**
Grand Total	**19**	**133**	**259**	**3,501**

Abalone Density: When data from all stations and zones are combined, the overall average density was 1,100 abalone per hectare (ab/ha) or 0.11 abalone per m^2 (ab/m^2) (Table 2). A total of 31,080 m^2 (3.1 ha) of bottom habitat was surveyed, which was 0.3 percent of the available abalone habitat for the three zones, excluding the Judith MR. The Southwest zone had the highest density of the three zones and the most completed transects. Abalone density in the Southeast zone was similar to the Southwest zone at 0.13 ab/m^2; however, in the Northwest zone, the density was much lower at 0.01 ab/m^2.

Table 2. Mean red abalone density overall and by zone.

Zone	Total Area (m^2)	No. of Abalone	Density (ab/ha)	Density (ab/m^2)	SE	No. of Transects
Northwest	**6,000**	**47**	**100**	**0.01**	**0.00**	**50**
Southeast	**7,800**	**1,044**	**1,300**	**0.13**	**0.03**	**65**
Southwest	**17,280**	**2,410**	**1,400**	**0.14**	**0.02**	**144**
Grand Total	**31,080**	**3,501**	**1,100**	**0.11**	**0.01**	**259**

Red abalone distribution at SMI during the 2007 survey was quite patchy, with emergent abalone density levels among stations ranging from zero to 11,800 individuals per hectare. Although 6,000 m^2 of area was surveyed in the Northwest zone, only 47 abalone were found. One pink abalone (*Haliotis corrugata*), measuring 172 mm, was found in the Southeast zone.

ARMP section 6.3.1 mentions the existence of no-take reserves at San Miguel Island as an additional insurance for continued abalone populations if stocks were depleted nearby under a possible future fishery. Two no-take reserves exist at SMI including the Judith Rock Marine Reserve (MR) in the Southwest zone and the Harris Point Marine Reserve (MR) located in Northeast zone (Figure 2). The Judith Rock MR extends from Judith Rock on the west end of Tyler Bight to Adams Cove near Point Bennett. A comparison of mean densities inside and outside of this reserve (the remainder of the Southwest zone) is provided in Table 3. The density in the Judith Rock MR was 0.11 ab/m^2, which was 0.04 ab/m^2 less than the rest of the Southwest zone outside the reserve. The Harris Point MR is located in the Northeast zone, which was not sampled during the random surveys. However, a timed-swim survey was conducted in the Harris Point MR at Nifty Cove during two dives.

Table 3. Abalone density comparison inside and outside of the Judith Rock Reserve.

Area	Total Area (m^2)	No. of Abalone	Density (ab/ha)	Density (ab/m^2)	SE	No. of Transects
Judith Rock MR	**5,040**	**567**	**1,100**	**0.11**	**0.02**	**42**
Outside MR (SW Zone)	**12,240**	**1,843**	**1,500**	**0.15**	**0.03**	**102**
Grand Total	**17,280**	**2,410**	**1,400**	**0.14**	**0.02**	**144**

Nifty Cove is located north of Cuyler Harbor in between Nifty and Hare rocks in the Harris Point MR. Five divers conducted two dives on the inshore and offshore reefs. No abalone were found on the offshore reef, with a total search time of 220 minutes. Twenty red abalone were found on the inshore reef, with a total search time of 266 minutes. The size frequency (Figure 3) shows mostly small abalone, less than 94 mm, with an average size of 34 mm. Emergent abalone were uncommon on the inshore reef, and rock crab, *Cancer antennarius*, were very common. Many abalone shells were found exhibiting signs of rock crab predation, which may be contributing to the low density of emergent abalone in the area.

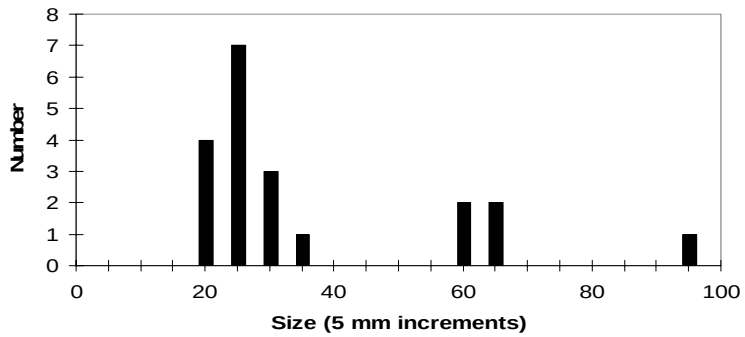

Figure 3. Size frequency of Nifty Cove red abalone.

Size Frequency: During the cruise, 2,504 red abalone were measured. The size frequency for all zones and each individual zone is depicted in Figures 4 and 5. Using the current northern California recreational minimum size (178 mm or 7 inches) and the past pre-1997 southern California commercial minimum size (197 mm or 7.75 inches), 70 percent and 41 percent of the observed emergent abalone were of legal recreational and commercial size, respectively. A possible increased minimum size limit (203 mm or 8 inches) was also evaluated, and 30 percent of emergent abalone were at or above that size limit.

The Southwest zone showed the greatest proportion of recreational and commercial legal size abalone and the Northwest zone the lowest (Table 4). Both the Southwest and Southeast zones showed similar size frequency distributions with most of the animals skewed towards the larger sizes. The Northwest zone did not show the same size pattern and had more individuals represented in the smaller size classes; although, the sample size was small (n=46) compared to the other zones.

Table 4. Percentage of abalone by size category and zone for survey years 2006 and 2007.

Size Category	2006			2007		
	NW	SE	SW	NW	SE	SW
Sub-legal (<178 mm)	71%	33%	27%	74%	33%	27%
Recreational (>=178 mm)	29%	67%	73%	26%	67%	73%
Commercial (>=197 mm)	11%	34%	42%	9%	35%	45%
Higher Size Limit (>=203 mm)	9%	23%	30%	4%	24%	34%

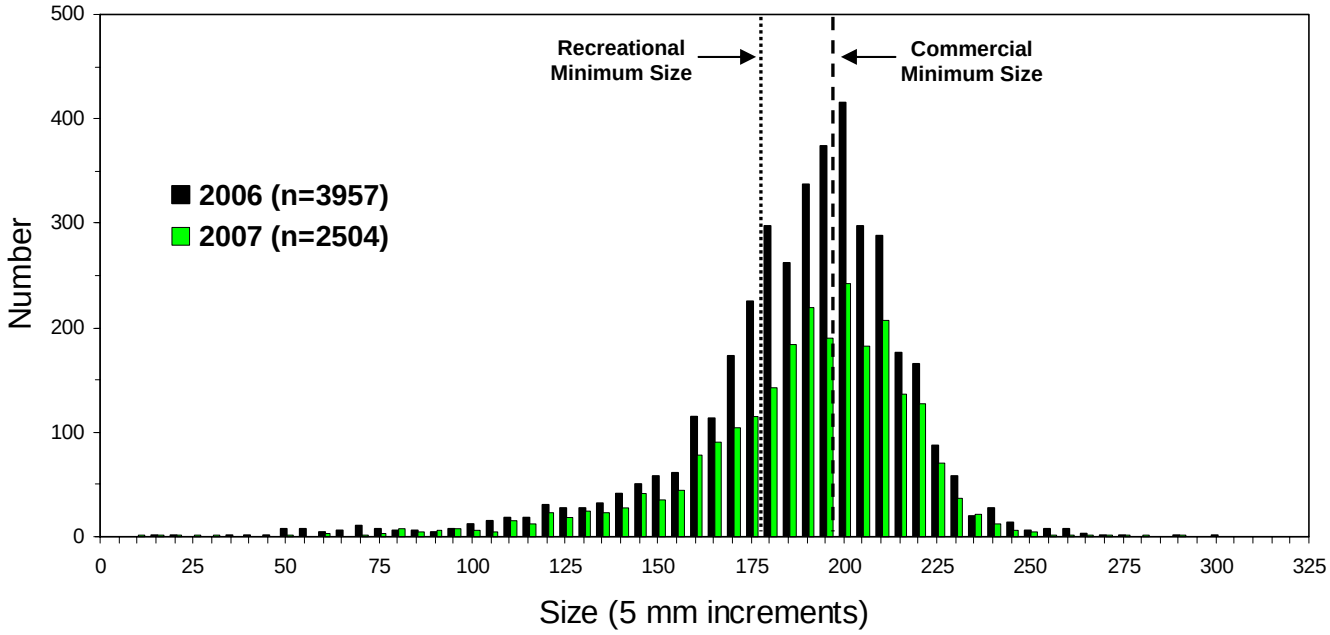

Figure 4. Overall size frequency for the San Miguel Island Survey.

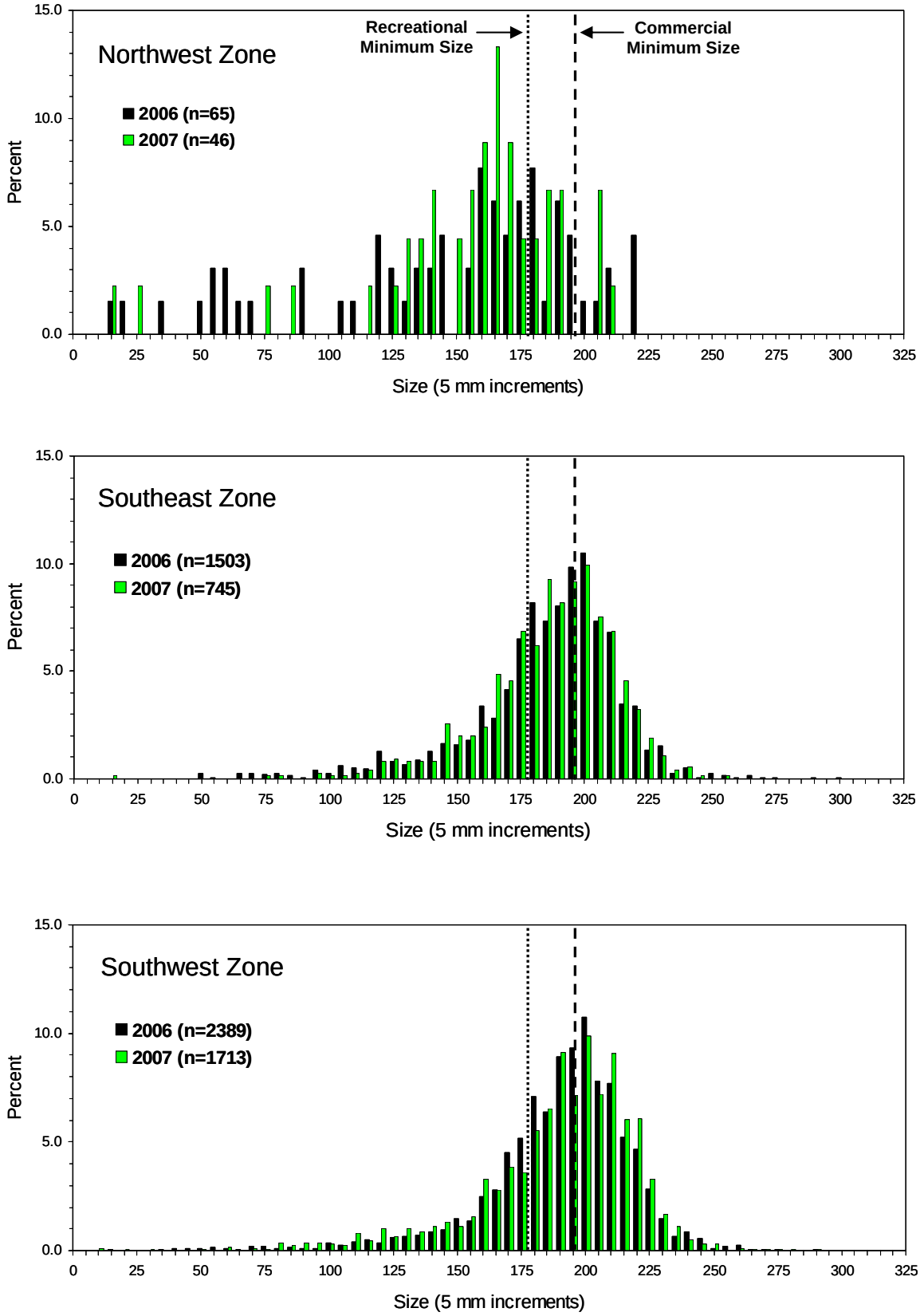

Figure 5. Percent size frequency of red abalone by zone.

Population Estimates: Abalone population was estimated by multiplying densities for each zone by abalone habitat calculated from kelp surveys of San Miguel Island conducted in the years 1989, 1999, 2002, 2003, 2004, 2005, and 2006 (Tables 5 and 6). The maximum coverage of kelp combined for all years, stratified to 50 feet water depth or less, was used for the calculations. Two sets of estimates were made using the mean density (Table 5) and the lower 95% confidence limit density (Table 6).

Table 5. Abalone population estimates using maximum kelp area (<= 50 feet) and mean density.

Zone	Maximum Kelp Area (m^2)	Mean Estimate	Abalone >= 178 mm (7 inches)	Abalone >= 197 mm (7.75 inches)	Abalone >= 203 mm (8 inches)
Northwest	**5,409,241**	**54,000**	**14,000**	**5,000**	**2,000**
Southeast	**2,770,267**	**360,000**	**241,000**	**126,000**	**86,000**
Southwest (excludes Judith Rock SMR)	**2,291,152**	**344,000**	**251,000**	**151,000**	**114,000**
Grand Total	**10,470,660**	**758,000**	**506,000**	**282,000**	**202,000**

Table 6. Abalone population estimates using maximum kelp area (<= 50 feet) and 95 percent lower confidence limit density.

Zone	Maximum Kelp Area (m^2)	95% Lower Limit Estimate	Abalone >= 178 mm (7 inches)	Abalone >= 197 mm (7.75 inches)	Abalone >= 203 mm (8 inches)
Northwest	**5,409,241**	**27,000**	**7,000**	**2,000**	**1,000**
Southeast	**2,770,267**	**213,000**	**143,000**	**75,000**	**51,000**
Southwest (excludes Judith Rock SMR)	**2,291,152**	**250,000**	**183,000**	**110,000**	**83,000**
Grand Total	**10,470,660**	**490,000**	**333,000**	**187,000**	**135,000**

The initial zones (Northwest, Southeast, and Southwest) were established for the purposes of conducting the San Miguel Island survey, and might be too large to be effectively used in management of a potential fishery. Two smaller zones were selected from the Southwest and Southeast survey zones in areas with relatively high abalone densities for possible use as management zones (Figures 6 and 7). A population estimate for these zones was calculated using maximum kelp area and average abalone densities in each management zone from surveyed stations (Table 7). Estimates for numbers of abalone in commercial size categories were made using percentages in size ranges for each survey zone (Table 8).

Table 7. Abalone population estimates for management zones 1, 2, 3, and 3a with maximum kelp area <= 50 feet.

Zone	Density (ab./m^2)	n	SE	Maximum Kelp Area (m^2)	Abalone Population Estimate	Abalone >= 178 mm (7 inches)	Abalone >= 197 mm (7.75 inches)	Abalone >= 203 mm (8 inches)
SW 1	0.17	56	0.03	879,834	150,000	111,000	71,000	57,000
SW 2	0.14	6	0.07	440,942	62,000	43,000	27,000	18,000
SE 3	0.25	31	0.05	1,324,232	331,000	209,000	113,000	83,000
SE 3a	0.20	43	0.04	1,786,170	357,000	225,000	121,000	89,000

Table 8. Percentage of abalone by size category for proposed management zones.

Size Category	Zone 1	Zone 2	Zone 3	Zone 3a
Sub-legal (<178 mm)	26%	31%	37%	37%
Recreational (>=178 mm)	74%	69%	63%	63%
Commercial (>=197 mm)	47%	44%	34%	34%
Higher Size Limit (>=203 mm)	38%	29%	25%	25%

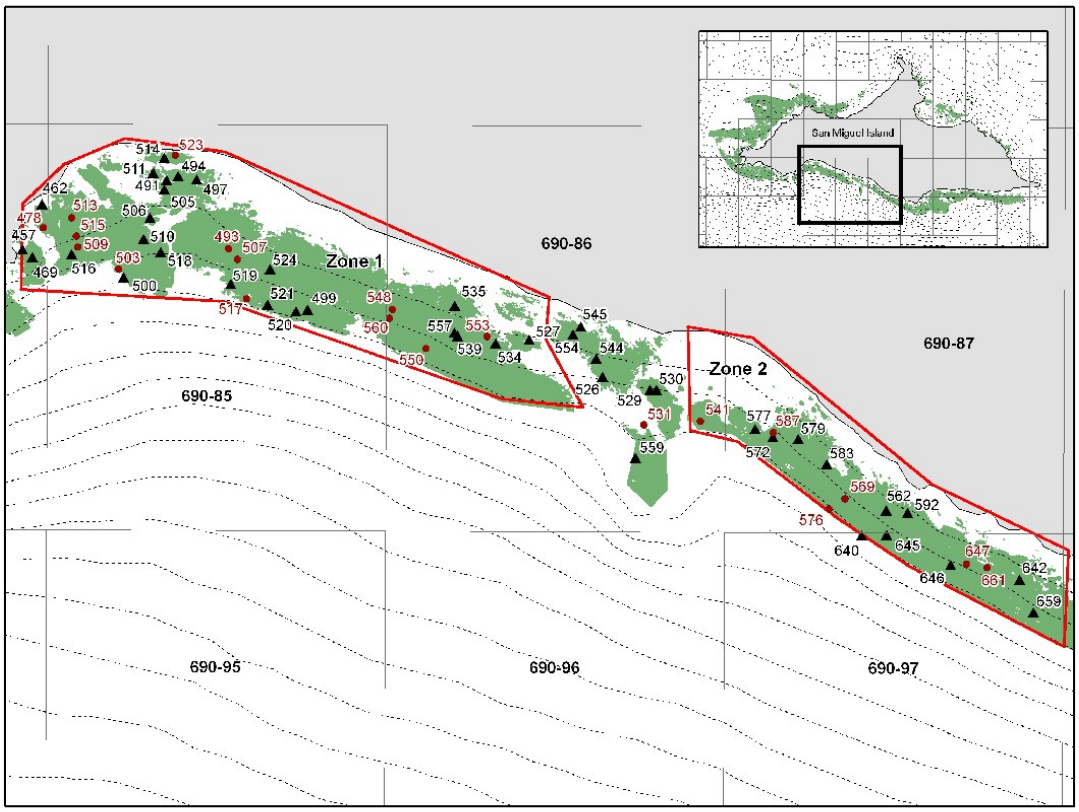

Figure 6. Southwest management zones 1 and 2.

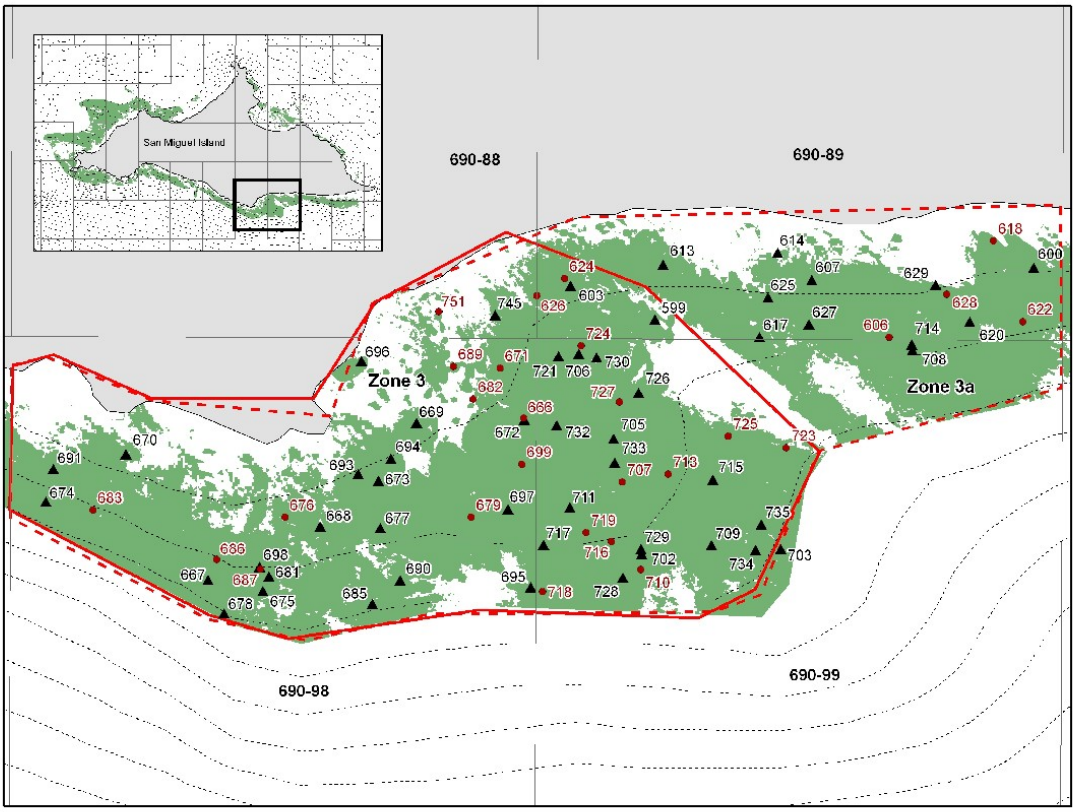

Figure 7. Southeast management zones 3 and 3a.

Observed Substrate and Relief for Survey Transects and Categorized Abalone

For all zones combined, the hard substrate was comprised of mostly reef (67 percent), with boulder (13 percent), and cobble (7 percent) being less common (Table 9). More boulder was observed in the Southwest zone (16 percent), and more cobble was observed in the Northwest zone (10 percent).

Mostly low relief was observed during the survey, comprising 68 percent of the bottom for all zones combined (Table 10). More low relief was observed in the Northwest and Southeast zones compared to the Southwest zone where more medium relief was observed. High relief comprised of a small percentage for each zone; however, more was recorded in the Southwest zone at 10 percent.

Table 9. Percentage of reef, sand, boulder, and cobble for surveyed transects at three zones.

Zone	Reef	Sand	Boulder	Cobble
Northwest	69%	10%	12%	10%
Southeast	77%	14%	6%	3%
Southwest	62%	14%	16%	8%
All Zones	67%	13%	13%	7%

Table 10. Percentage of low, medium, and high relief type for three zones at San Miguel Island.

Zone	Low	Medium	High	Unrecorded Relief
Northwest	85%	11%	4%	0%
Southeast	87%	11%	2%	0%
Southwest	54%	35%	10%	1%
All Zones	68%	24%	7%	1%

The substrate and relief data collected for 2006 and 2007 was useful in determining proportions of habitat at the island, but it was limited in its use for describing abalone habitat. In 2007, divers recorded additional information for each abalone including the substrate and relief type that it inhabited. This revealed a more defined view of the habitat type abalone preferred during the survey. Divers were able to categorize 97 percent of the counted abalone.

For the Southeast and Southwest zones, 69 percent of the abalone were on reef and 31 percent were on boulder (Table 11). In the Northwest zone, 53 percent of the abalone were on reef and 47 percent were on boulder. Abalone were not found on cobble in any of the three zones. Abalone were mostly on low relief for all zones combined and in each individual zone (Table 12). Some abalone inhabited medium relief, which was more common in the southern zones compared to the northwest zone. Few abalone were found on high relief; and made up a small percentage of the overall totals.

Table 11. Substrate categories by percentage for abalone in all zones.

Zone	Count	Reef	Boulder	Cobble
Northwest	47	53%	47%	0%
Southeast	1022	69%	31%	0%
Southwest	2327	69%	31%	0%
All Zones	3396	69%	31%	0%

Table 12. Relief categories by percentage for abalone in all zones.

Zone	Count	Low	Medium	High
Northwest	47	85%	13%	2%
Southeast	1022	77%	23%	0%
Southwest	2327	68%	27%	5%
All Zones	3396	71%	26%	3%

Abalone Clustering or Aggregation

Abalone aggregation is a very important factor in predicting fertilization success rates. Some measure of the number and size of aggregations coupled with the overall density are very important factors in characterizing the health and status of the resource. Abalone clustering was roughly measured by analyzing the frequency of abalone in the smallest spatial resolution possible from the survey at $10m^2$ (Table 13). This crude method was limited to showing the percentages of truly solitary abalone in the sampled population as well as a general proportion of abalone that might be aggregated within the spatial resolution used. Approximately 9 percent of the counted abalone were solitary, however, 69 percent of the abalone were in groups of four or more.

Table 13. Frequency of abalone group sizes per 5 x 2 meter segment ($10\ m^2$) for all zones combined.

Group Size	Count of Segments	% of Total Segments	Total Abalone	% of Total Abalone
0	2162	69.6%	0	0.0%
1	317	10.2%	317	9.1%
2	214	6.9%	428	12.2%
3	112	3.6%	336	9.6%
4	79	2.5%	316	9.0%
5	49	1.6%	245	7.0%
6	29	0.9%	174	5.0%
7	22	0.7%	154	4.4%
8	30	1.0%	240	6.9%
9	18	0.6%	162	4.6%
10	18	0.6%	180	5.1%
11	9	0.3%	99	2.8%
12	8	0.3%	96	2.7%
13	9	0.3%	117	3.3%
14	4	0.1%	56	1.6%
15	2	0.1%	30	0.9%
16	4	0.1%	64	1.8%
17	5	0.2%	85	2.4%
18	2	0.1%	36	1.0%
19	2	0.1%	38	1.1%
20	1	0.0%	20	0.6%
21	6	0.2%	126	3.6%
26	2	0.1%	52	1.5%
29	1	0.0%	29	0.8%
30	1	0.0%	30	0.9%
32	1	0.0%	32	0.9%
39	1	0.0%	39	1.1%
Total	3108	100%	3501	100%

Abalone aggregation was measured in a more direct fashion in the 2007 survey by the addition of a nearest neighbor distance study to a subset of the overall survey transects. This study was conducted by Cynthia Button of Scripps Institute of Oceanography.

Nearest neighbor distance surveys were done in conjunction with some of the density transect surveys in each of the three survey zones. This allowed the aggregation measure to be related to survey density. Nearest neighbor distances were measured between the closest abalone to a random point and its nearest neighbor. Only emergent abalone were used for these surveys. Aggregation sizes were determined by counting all abalone within 2.5 m from the first abalone closest to the random point. Due to the very low density of sampled abalone in the NW zone, only nearest neighbor distance data for the two southern survey zones were used for SMI.

Besides San Miguel Island, nearest neighbor distance surveys were also conducted for red abalone in northern California (Van Damme State Marine Conservation Area, Ocean Cove, Fort Ross State Marine Conservation Area), central California (Hopkins Marine Reserve), and for pink abalone off Point Loma. This provides a comparison of average distance to nearest neighbors and aggregation size for a wide range of population density.

The results for SMI show that the average transect density (where nearest neighbor surveys were conducted) were 1,061 ab/ha in the SW zone and 1,755 ab/ha for the SE. The average nearest-neighbor distances were 1.9 m (SD = 1.4 m) in the SW and 1.5 m (SD = 1.4 m) in the SE. The average group sizes were 3.9 (SD = 4.0) in the SW and 4.1 (SD = 4.5) in the SE. Both aggregation estimates were highly variable.

When comparing among northern, central, and southern California populations (by site), the average distances between nearest neighbors and aggregation sizes in the populations are strongly correlated with density (Figures 8 and 9).

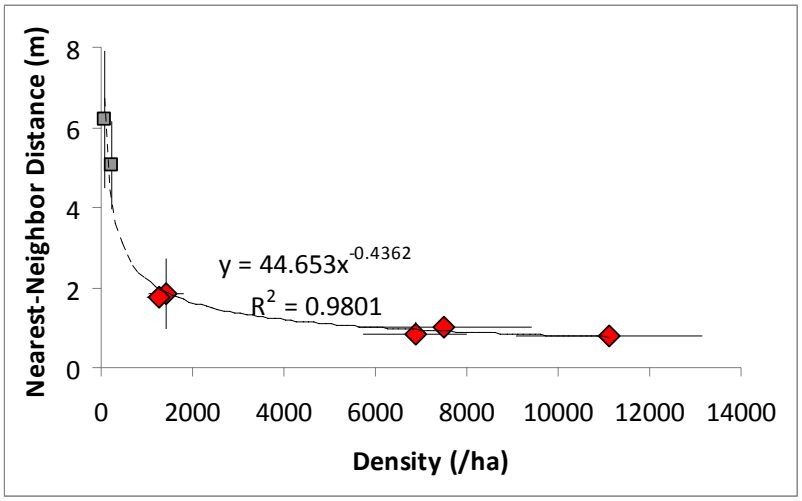

Figure 8. Mean nearest neighbor distance versus red abalone density at each site. The pink abalone population is represented by the gray boxes, and the red abalone populations are represented by the red diamonds.

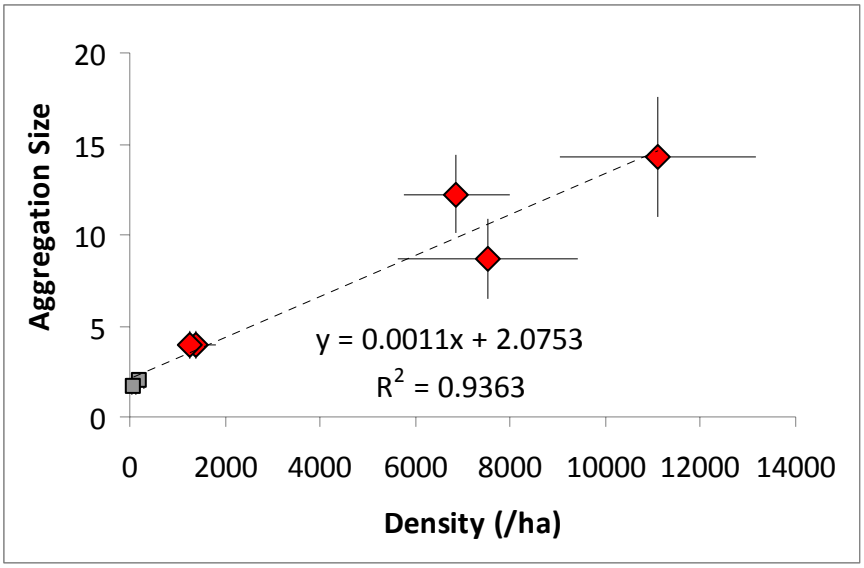

Figure 9. Mean aggregation size versus red abalone density at each site in Table 1. The pink abalone population is represented by the gray boxes, and the red abalone populations are represented by the red diamonds.

The average nearest-neighbor distance increases dramatically at densities below approximately 2,000 ab/ha. Similarly, the average aggregation size is less than 4 at densities close to 2,000 ab/ha. What this means for SMI populations is that at current densities, average nearest neighbor distance is still close enough for potentially successful spawning aggregations. However, the size of the average aggregation of approximately four abalone is of concern, given a 1:1 sex ratio for red abalone and the dramatic decrease in probability of having at least one of each sex in groups of less than four individuals.

Analysis of SMI Abalone Fecundity

Females ranged in shell length from 104-239 mm with an average shell length of 180 mm. Total number of eggs for female abalone in survey years 2006 and 2007 are shown in Figure 10. Typically, the larger the female, the more mature eggs they produce. Gonad index from San Miguel Island is plotted with abalone samples from Van Damme in Northern California (Figure 11). Samples at Van Damme were taken at approximately the same time of year as SMI samples. Gonad index from SMI abalone are higher on average than Van Damme abalone. SMI abalone have a higher number of mature eggs compared to Van Damme abalone of similar length, but fall within the same correlative pattern.

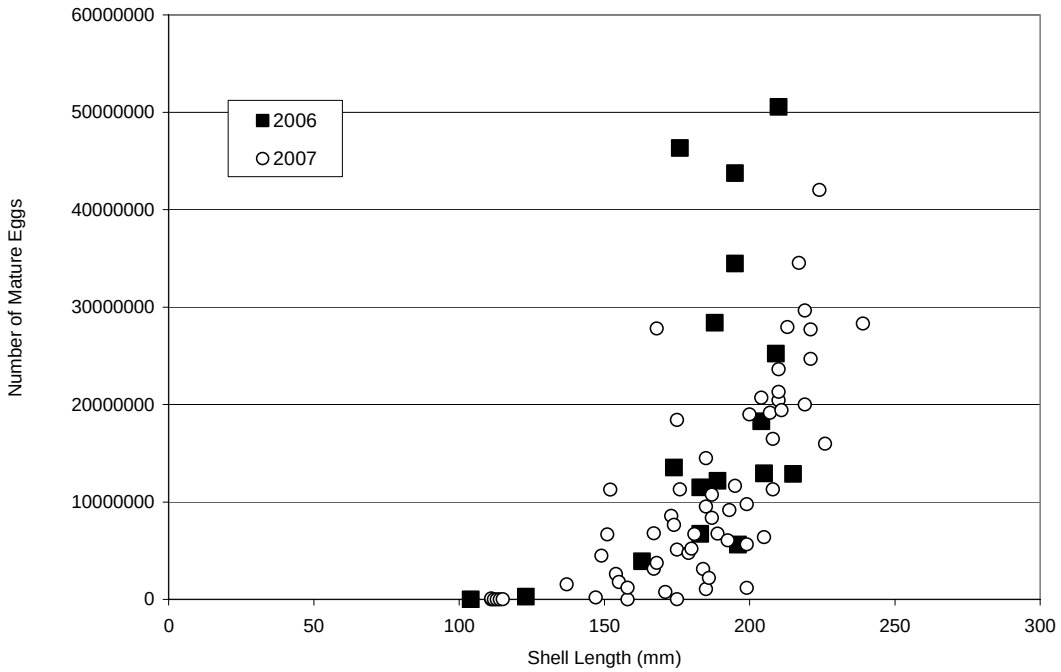

Figure 10. Number of mature eggs of female abalone at San Miguel Island for survey years 2006 and 2007.

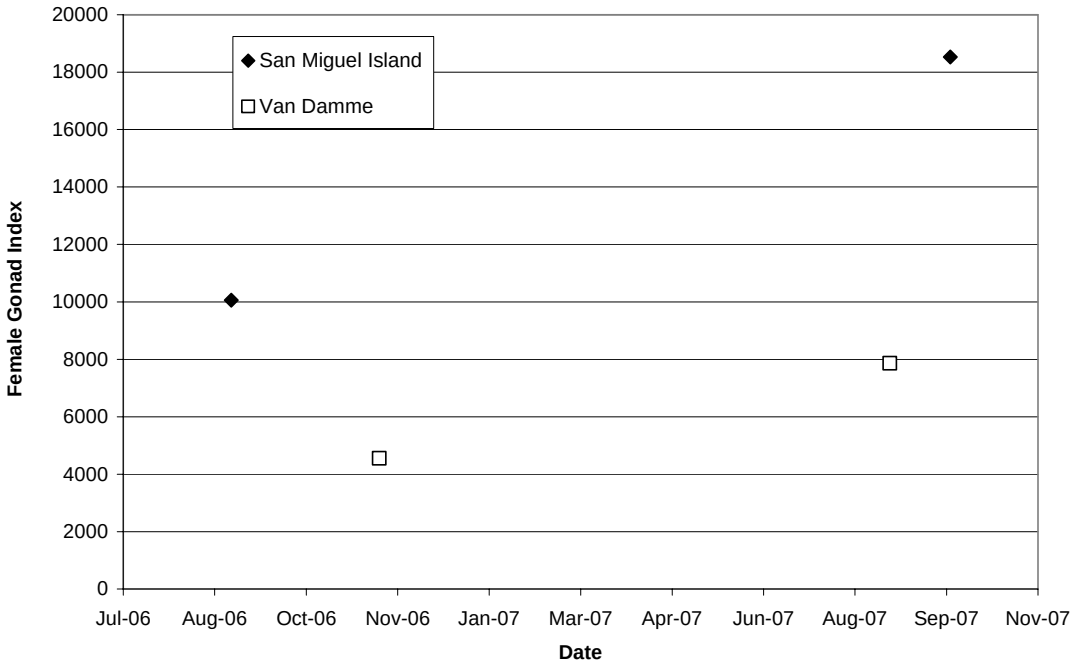

Figure 11. Female Gonad Index at San Miguel Island and Van Damme for survey years 2006 and 2007.

Comparison of 2006 and 2007 surveys

More surveys were completed in 2006, 202 stations and 400 transects, than in 2007,133 stations and 259 transects. Fewer abalone were counted in 2007 than in 2006, 3,501 and 5,695 respectively, which was a 39 percent decrease; however, 17,000 m^2 less area was surveyed in 2007. This was 35 percent less surveyed area than in 2006.

Although there were fewer completed transects in 2007, the abalone densities overall and between zones, in the Judith Rock MR, and proposed management zones were similar. For the three zones combined, the 2006 surveys resulted in 1,200 ab/ha, which was 100 ab/ha more than the 2007 survey. The densities in the Northwest zone were low for both years at 160 and 100 ab/ha for 2006 and 2007, respectively. Abalone density was greater in 2006 for the Southwest zone at 1,600 ab/ha, but less in the Southeast zone at 1,100 ab/ha.

Using a Mann-Whitney test, no significant differences were found between the years 2006 and 2007 for station densities for all zones combined (n=202 for 2006, n=133 for 2007, P=0.76), in the Northwest zone (n=30 for 2006, n=25 for 2007, P=0.51), Southeast zone (n=79 for 2006, n=33 for 2007, P=0.40), or Southwest zone (n=93 for 2006, n=75 for 2007, P=0.84).

Abalone size between the two survey years was similar. Size frequency histograms for the two survey years were very similar in shape and proportion even though the sample size for 2006 was almost 1,500 abalone greater (Figures 4 and 5). Table 4 shows similar proportions of size categories sub-legal, recreational, commercial, and higher size limit for both 2006 and 2007. In 2007, survey results indicated that both the commercial and higher limit sizes for both the Southeast and Southwest zones slightly increased.

Using a Mann-Whitney test, no significant differences were found between the years 2006 and 2007 for abalone size for all zones combined (n=3957 for 2006, n=2504 for 2007, P=0.09), in the Northwest zone (n=65 for 2006, n=46 for 2007, P=0.77), Southeast zone (n=1503 for 2006, n=745 for 2007, P=0.72), or Southwest zone (n=2389 for 2006, n=1713 for 2007, P=0.15).

Due to similar densities between all zones for both the survey years, the population estimates were also similar. For the Southeast zone, the mean estimate was 13,000 less in 2007. For the Southwest zone, excluding the MPA surveys, the mean estimates indicated a 66,000 decrease in abalone from the 2006 surveys, which was a drop of about 16 percent. In the 2007 survey, only 47 abalone were counted in the northwest, which resulted in a small mean estimate of only 54,000 abalone. This contributed to the lower estimates in 2007 at 758,000 abalone compared to 910,000 in 2006. In addition, the 2007 calculations were based on a smaller extent of kelp area of 10.5 million ha than in 2006, which was 14 million ha. This is due to stratifying the sampling depths to 50 feet of water depth or less.

Proportions of substrate and relief type for the 2006 and 2007 surveys were similar. Reef was the dominant substrate type for combined zones at 67 percent in 2007, and 64 percent in 2006. The proportion for individual zones was mostly unchanged except for an increase in reef for 2007 of 10 percent in the Southwest zone. In 2007, low relief made up 68 percent of the survey transects followed by medium at 24 percent, and high relief only making up 7 percent. The 2006 survey showed almost the same proportions of relief for low (68 percent), medium (21 percent), and high (8 percent). Zonal proportions were also similar in the Southwest zone. Low relief was recorded about 10 percent higher in 2007 for the Northwest and Southeast zones, with less medium and high relief.

A comparison of abalone aggregations between the survey years showed that abalone were encountered in 30 percent of the segments for both datasets. Solitary abalone made up a small proportion of the groups for both years, accounting for only 9 percent of the abalone in 2007 and 8 percent of the abalone in 2006. In addition, proportions of abalone in groups of 10 or more were similar for both years (28 percent in 2006, 32 percent in 2007).

Conclusion

The second survey year at San Miguel Island is now complete, and the results indicate mostly similar outcomes between the two survey years despite a smaller effort in 2007. A third survey year should further increase our confidence in the data collection methods, analysis, and collaborative process. Similar to the 2006 survey, the information gained in 2007 has helped achieve the four survey objectives associated with fishery development mentioned in the beginning. If results from the upcoming 2008 survey year are within a biologically plausible range considering the underlying population dynamics of the stock and the results of the preceding years, the potential usefulness of the annual values for trend analysis would add a new dimension to the survey usefulness.

A third major survey effort will add to our understanding of the status of the abalone population at San Miguel Island. Given the time required for a successful recruitment event to be detectable in the population, we expect the unfished population to remain fairly stable until three or four years after such an event occurs. If a third survey year indicates continued stability in the population, we will have a larger sample size with which to compare to future years when a strong recruitment event might occur. This could form the basis for a “before and after” type of analysis with narrower confidence bounds, allowing significant abundance changes to be detected with greater confidence.

The 2006 and 2007 surveys have provided abalone abundance and size data that will be useful in the development of a TAC component for fishery alternatives. Overall population estimates based on density and kelp coverage as a proxy for habitat were generated for the purposes of TAC discussion and development. These surveys have provided a foundation for continued collaborative surveys in the future.

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The 2008 San Miguel Island abalone survey took place during the last week of September. During the five day cruise 31 divers and seven vessels participated in the survey. One hundred seventy five survey stations were sampled in the two southern survey zones (93 stations in SE, 82 stations in SW). A total of 6470 abalone were encountered during transect surveys (6465 red, 4 pinto, and 1 flat). Approximately 42,000 square meters of bottom were surveyed yielding an overall density of 1539 ab./hectare (0.1539 ab./sq. m). Table 1 shows the total abalone, area surveyed, and density by zone and overall.

Table 1. Summary of completed grids, stations, transects, and total abalone, area, and density per survey zone.

Zone	Total Grids	Total Stations	Total Transects	Total Abalone	Total Area (m^2)	Density (ab./ha)
Southeast	**8**	**93**	**186**	**2,910**	**22,320**	**1,304**
Southwest	**7**	**82**	**164**	**3,555**	**19,690**	**1,806**
Grand Total	**15**	**175**	**350**	**6,465**	**42,000**	**1,539**

A total of 5,571 abalone were measured during the survey. The overall size frequency is shown in Figure 1.

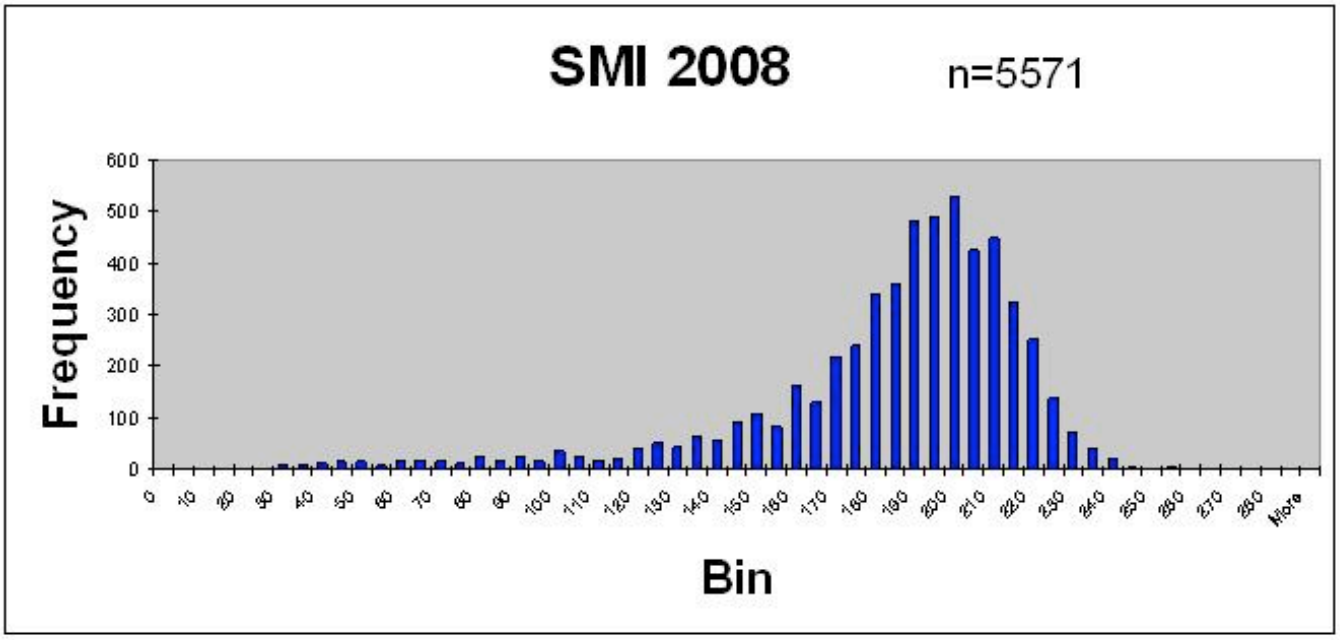

Figure 1. Overall size frequency for 2008 SMI survey.